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JULY, 1936

THE PRESENT TECTONIC STATE OF THE EARTH[1]

HANS STILLE[2]
Berlin, Germany

ABSTRACT

The present is the key to the past, but the past is generally believed to have been made up of relatively long and quiet epeirogenic periods separated by shorter times of orogenic disturbance. It is therefore important to decide whether the present is orogenic or non-orogenic.

In Central Europe, where the data are numerous, it can be shown that crustal movements of the present are perhaps ten times as great as those of the past, but the rate of movement is nevertheless small, and the comparison is less exact than could be wished.

The peri-Pacific region is in general better suited than Europe for a study of the problem, and California offers particular advantages. A compilation of the results of observations made by the writer and others in California shows that this region suffered a major orogenic disturbance in the Middle Pleistocene, at a time probably not more than 250,000 years ago. For this disturbance the writer proposes the name *Pasadenan orogeny*.

A study of this orogeny and of events following it suggests that, though its climax is long past, this disturbance has not yet completely died out. If this conclusion is warranted, the present does not truly reflect either the epeirogenic or the orogenic periods of the past, but is more disturbed than the one, and less disturbed than the climactic stages of the other.

I. INTRODUCTORY REMARKS CONCERNING "OROGENIC" AND "NON-OROGENIC" TIMES

Continuous movement affects the earth's crust; its tectonic growth has gone on uninterruptedly. But "uninterruptedly" does not mean "uniformly." Instead there have been very long periods characterized by relative quiet, by the so-called "epeirogenic processes"; these were essentially uplifts, subsidences, and broad warpings of

[1] Translated from a special publication of the *Sitzungsberichten der Preussischen Akademie der Wissenschaften*, Phys.-Math. Klasse, XIII (1935). Translation by Hans Ashauer, with the assistance of R. D. Reed. Parts III and IV, which deal with conditions in Central Europe, have been abbreviated with the consent of the author. Manuscript received, January 15, 1936.

[2] Geologisch-Paleontologisches Institut und Museum der Universität Berlin, Invalidenstrasse 43, Berlin N. 4.

large units of the earth's crust, with little or no change in the tectonic composition of the earth ("evolutionary times"). They alternated with relatively short periods during which there was widespread deformation of the crust ("revolutionary times"). During the latter occurred what we designate, not very happily, as "orogenies" ("mountain-buildings").

The term "mountain-building,"[3] like many other geological terms, comes from the vocabulary and the circle of ideas of the miner. When the miner says "mountain," he refers not to the topographic form, but to the rock; and "mountain-building" means to him the processes that gave the rocks their present attitudes. "Mountain-building" was introduced into geology with this meaning.

So long as it was believed that the actual mountains of to-day are the result of folding and other dislocations, the term "mountain-building" had the same significance, tectonically and topographically. And it is still obviously true to-day—though contrary opinions have been expressed—that mountain-building in the tectonic sense generally leads at first to mountain-building in the topographic sense. If the stratified rocks of the crust are compressed by mountain-building—in the tectonic sense—to a fraction, perhaps a third or a half or even less, of their former areal extent, the decrease horizontally must be balanced by an increase vertically. From isostatic considerations this vertical increase must take place partly in a downward, but much more strongly in an upward direction. The great denudations that follow foldings give clear testimony to the orogenic uplift. Very often the post-orogenic deposits lie on strata which, before the orogeny, had been buried in the geosynclines beneath thousands of feet of younger rocks. The folding must have brought them upward into the region of denudation.

The mountains resulting directly from an orogeny may be very ephemeral. This fact is proved by the consideration that, in spite of the orogenic uplift of an area, the sea may reappear very soon, in a geologic sense, in the area of uplift. Denudation and subsidence have caused the topographic elevations to disappear.

As a matter of fact, orogeny, in the tectonic sense, generally fails as an explanation for the existence of the topographically great mountains of the earth, such as the Alps of Europe or the Cordilleras of North America. These mountains exist—or still exist—as a result of post-orogenic *en bloc* movements, for the most part still going on, and belonging to the category of epeirogenic processes. Thus arises

[3] This paragraph applies to German conditions more certainly than to English.—H. A.

the terminologic contradiction, that the mountains as we see them to-day owe their origin not to what is called orogeny, but to an entirely different type of movement that is to be strongly contrasted with the orogenic process. Orogeny and topographic mountains are indirectly connected in the sense that the orogenic units, at least in the beginning, coincide with the units of epeirogenic movement. Thus the Alps are a unit not only morphologically but also in relation to orogenic history. But the fact that the Alps are high mountains to-day is due solely to epeirogenic processes. There are cases, on the other hand, in which areas of varied orogenic history have acted as epeirogenic units and thus united morphologically into a single mountain area. The Rocky Mountains furnish an example, since they include not only belts that are tectonically young, but also other areas that became consolidated very early (Colorado Plateau).

In any event the terms "orogeny" and "mountain-building" are so fixed in geological terminology, and justifiably so according to the principle of priority in scientific nomenclature, that any proposal to expunge them would fail to receive general approval. I believe that in doubtful cases one may assist himself in distinguishing orogenic from epeirogenic events if he mentally translates orogenic as "structogenic."

It has been, and to some extent still is to-day, the task of geological research to determine the dates of the individual orogenic periods; that is, the scheme of orogenic episodes in the framework of the steadily evolving tectonic history. In the *Grundfragen der vergleichenden Tektonik* in 1924, I was able to list approximately 30 orogenic periods for post-Cambrian time, but realized (p. 63) that my list could serve only as a foundation for what may eventually become a truly satisfactory tabulation of the orogenic phases of the past. With the greater interest in the exact dating of these phenomena that has existed since that time, about a dozen new phases, none of major importance, have been added to the list. Some of them were suspected in 1924 but seemed unsatisfactorily attested (pre-Ordovician, early Ordovician, middle Lower Carboniferous, end of the Carboniferous, intra-Lias, Middle Eocene); one or two others, tectonic "outsiders," are known only in a single locality. Figure 1 shows the times of the orogenic episodes thus far known.[4] In it the attempt is also made to suggest the relative importance of the different phases, and to distinguish classes of intensity. The shortest lines indicate orogenies that are known from a single locality, or at most are nowhere of much importance. The

[4] F. Lotze made a similar attempt in 1927, using the data of the *Grundfragen der vergleichenden Tektonik.*

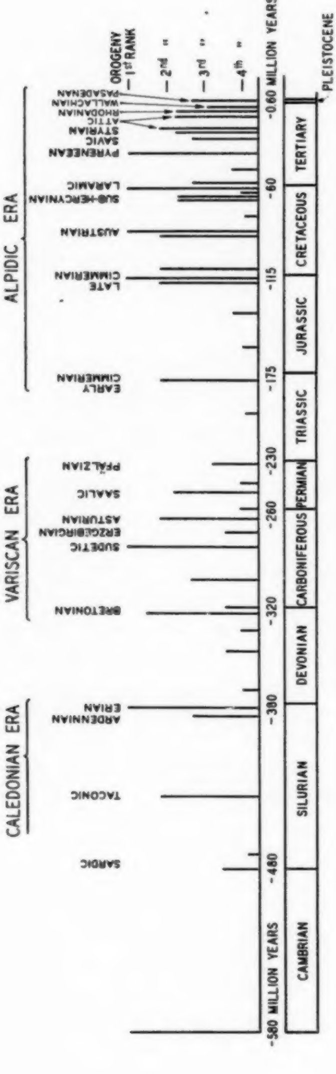

FIG. 1.—Orogenic disturbances of the past.

longest lines designate the great folding periods, and intermediate lines designate intermediate intensities. These quantitative estimates are of course merely suggestive, not final.

Although the orogenic movements took place at the same time in different areas, they were strong (Alpine type) only in certain mobile belts which had developed as orthogeosynclines. Less intense orogenies (Saxon type) may take place in areas prepared by having been "special basins" (parageosynclines) in regions that had become consolidated earlier. There are wide areas, finally, in which orogenic movements failed, or acted weakly; epeirogeny continued in them, though with heightened intensity. For these mainly epeirogenic, or moderately orogenic movements during the orogenic periods the term, "synorogenic," has been used. Here we are dealing with boundary cases between orogeny and epeirogeny.

For a decision as to the orogenic or epeirogenic character of a certain period of the earth's history, many regions may be poorly adapted even if strata of the time in question are well represented. Rather we must seek the answer in areas where orogeny was fairly intense, and not merely synorogenic. After all, in accordance with the previous discussion, we should expect some contemporaneous synorogenic disturbances in those regions that were not affected by a major orogeny.

The Sudetic orogeny, for example, which has great importance over broad areas of the earth, is represented nowhere in North America by an observable major unconformity, although there are some indications that a concealed unconformity may exist in certain regions where the Carboniferous strata are deeply buried by younger deposits. Synorogenic movements dating from this time are to be recognized everywhere in this continent, especially in areas that became consolidated in the pre-Cambrian. They were due to sudden increases in the intensity of long-continued uplift and warping.

Reinforced epeirogenic movements, locally indistinguishable from truly orogenic movements, are known in the Mid-Continent of North America for the Taconic orogeny (between Ordovician and Silurian), for the younger Caledonian (between Silurian and Devonian), for the Bretonian (late Devonian-pre-Carboniferous), and the Asturian (later Upper Carboniferous). In many cases these synorogenic unconformities have been discovered by the drilling of oil wells.

The succession of transgressions and regressions of the past makes evident a sort of rule, namely, that the orogenic periods caused an increase in the area of the continents, not merely by the orogenic uplift of the folded belts but also by an accentuated uplift of the

regions that lie outside the folded areas, that is, by a *synorogenic strengthening of epeirogenesis* (Stille, 1924).

In preparation for our discussion of the recent movements of the earth's crust, another subject requires comment. Epeirogenic movements are rightfully called "secular," that is, lasting for "centuries," a geological century being of the order of a million years; but during these long periods the movements do not proceed uniformly, being now strengthened, now enfeebled, and at other times going by jerks. This is shown by uplifted terraces, cut in the land by the sea from time to time during uplift. They represent intervals during which the sea-level remained constant for a time, and thus indicate pauses during uplift; while the vertical distances between terraces reflect the times between terrace-cutting, during which the land moved upward more continuously and more rapidly.

II. PROBLEMS

How are we to describe the present tectonic condition of the earth, in comparison with the conditions known for the past? Are we living in an orogenic or a non-orogenic period?

This question is important not only for its bearing on Recent tectonics, but also in deciding whether we should use the present conditions of the earth to give us an idea of the conditions of the past during a non-orogenic—that is, with respect to the time involved, a *normal*—or an orogenic—*abnormal*—period.

The generally accepted idea, to which I inclined at first (1918, 1924), is that we are living in a non-orogenic time, that is, in a time of purely epeirogenic movements; if this is true, Recent movements would furnish us with an example of the events of a normal period of the earth's history.

Processes are of course taking place to-day that must be called orogenic if we define the term strictly as "structure-changing." I have in mind the horizontal and vertical movements during earthquakes, amounting in general to only a few meters. Accepting the idea that we are living in a non-orogenic period, I have even taken these movements as an indication (1918, p. 10; 1924) that epeirogenic movements may be accompanied by small faults.

Since then I have come more and more to doubt the idea that the present is normal in a tectonic sense, and I expressed these doubts in Leningrad during the year 1931 in a speech at the Congress of the Seismological Institute of the Russian Academy of Sciences. My doubts were increased during 1933 by some studies I was able to make in western America, especially in California. In the meantime

Bucher (1933, p. 482) has denied that the present is a non-orogenic period, representing it as "a late stage in a compressional phase of crustal deformation."

III. RECENT TECTONICS OF CENTRAL EUROPE

In the character of its movements Central Europe shows epeirogenic features, but of a type that characterizes many regions of German-type tectonics, and may be called "buckling." Compared with the long, Alpine-type geosynclines and geanticlines, the rising and sinking areas in regions of "buckling type" are more irregularly distributed, and are more nearly circular in shape. Old positive epeirogenic units in Central Europe include the Baltic shield, the Rhenish and the Bohemian massifs. Old negative areas (parageosynclines) include the Lower German basin with the embayment of the Lower Rhine and the sub-Hercynian basin as constituent parts, the Hessian strait, the Upper Rhine graben, and the South German basin. These units have a long geological evolution behind them. The contrast of Rhenish massif and Hessian strait, for example, began in the Upper Permian and has persisted ever since.

The secular movements that have affected the Baltic shield since the Pleistocene and still affect it, are well known and have been described in detail. We know that the Baltic shield has not been raised equally everywhere, in the manner of a rigid block, but that it has been warped into the shape of a shield. The uplift amounts to-day to $\frac{1}{2}$ centimeter a year at Stockholm, and to a little more than 1 centimeter in the northernmost part of the Gulf of Bothnia. South of the Baltic shield there are subsidences of comparable amount. The subsiding region covers a great part of northern Germany. To form an idea of the amount of subsidence in this area, we may imagine it stripped of Pleistocene sediments, the thickness of which is known as a result of drilling. If this were done, the North Sea and the Baltic would transgress northern Germany to a line south of Berlin ("diluvial depression" of O. von Linstow, 1922). During the Pliocene this area was a part of the continent, but during the Pleistocene and afterwards, subsidence has carried the old surface far below the level of the sea. Along the German sea coast this subsidence is still going on at the rate of 1–2 millimeters per year.

The basin of the Lower Rhine, a part of the North German lowland, is situated north of the Rhenish massif. The contrast between these areas has existed since an early period of the earth's history. Geodetic measurements of the last 25 years indicate an uplift of the Rhenish massif of approximately 1 millimeter per year.

In the upper course of the Rhine, Wilser (1929) has distinguished three areas between Basel and Mainz: a southern and a northern area that are undergoing erosion and a middle area that is sinking and was marshy before the flow of the Rhine was regulated. Basing his conclusion on two series of levels made 50 years apart, Wilser has shown (1932) that the warping in this region amounts to about 1 millimeter per year.

From geodetic work in Bavaria we know something of the rate of sinking in the sub-Alpine region. The amounts vary from place to place, being from 1 to 6 centimeters in 20 years (Schmidt, 1919). The measurements suggest that a broad syncline is developing. By this process Munich has moved about 12 centimeters nearer to the Alps during the last 50 years.

In summary, throughout most of Central Europe movements of uplift and subsidence amount to a few millimeters a year. The Baltic shield is exceptional, with an uplift exceeding 1 centimeter a year. In this case, however, special conditions ("ice-isostasy") may be a complicating factor in the epeirogenic uplift.

The asymmetrical distribution of rising and sinking areas shows that the recent movements are warpings ("undulations") of the kind that distinguish epeirogenic movements.

Areas of uplift and subsidence are often related; for example, the rising Baltic shield and the sinking German plain on the south, or the rising Rhenish massif and the sinking areas on the north and west.

The recent uplifts and sinkings are the continuation of older epeirogenic movements. The Baltic shield has been a positive area since the end of the Paleozoic, and the Lower German basin a negative one. Likewise, there has been a contrast since very ancient times between the rising Rhenish massif and the subsiding basin of the Lower Rhine; the local movements of the Upper Rhine reflect older warping oblique to the Rhine Valley, and the sub-Alpine depression occupies the site of the old Molasse basin.

IV. AMOUNT OF RECENT TECTONIC MOVEMENTS OF CENTRAL EUROPE COMPARED WITH EPEIROGENIC MOVEMENTS OF OLDER GEOLOGICAL PERIODS

When we try to decide whether the present is orogenic or nonorogenic, the question rises as to the rate of movement during the epeirogenic periods of the past. So far as the upward epeirogenic movements are concerned, the question can not be answered, since the rising land is commonly eroded and the indications of uplift are destroyed. All that can be said is that there must have been an

approximate correspondence between uplift and subsidence, since otherwise the areas of denudation could not have supplied enough sediment to make the thick strata of the subsiding areas.

It is easier to determine rate of sinking during the past, so far at least as average rate of sinking during long periods is concerned. It may be said, in fact, that the thickness of strata corresponds approximately with the amount of sinking. The rate of sinking is thus the quotient obtained by dividing the thickness of the strata by the time required for their deposition. Some corrections are needed, of course, since thickness of strata corr⁻sponds to amount of sinking only if the area of deposition was filled both at the beginning and end of the period of deposition; but if we choose long periods, the correction tends to become negligible.

When we divide the thickness of strata in old geosynclines by the time that we suppose their deposition to have required, we get for the deepest geosynclines figures of the order of a few tenths of a millimeter per year.

The greatest sinkings, determined from the local amount of sinking and the size of the sinking area, undoubtedly are found in the great orthogeosynclines of the earth. So far as the amount of local sinking is concerned, however, these are equaled by many of the smaller German-type basins (parageosynclines). In fact the most extreme sinkings, in terms of thickness of sediment and time required for its deposition, seem to have occurred in the parageosynclines, if we expect the foredeeps of the Alpine geosynclines. Consider, for example, the supposed 20 kilometers of Old Red sandstone in western Norway, or the more than 5,000 meters of Pliocene in the Ventura Basin of California (Reed, 1933, p. 228), or the 5,000 meters of continental Upper Triassic of New Jersey. Even the German Trias over much of Germany is hardly thinner than the Alpine facies of the Alps. During middle Upper Carboniferous the rate of sinking in the small Saar Basin was nearly as rapid as that of the great sub-Variscan foredeep in Germany (Stille, 1929).

The amount of recent crustal warping in Central Europe is a few millimeters per year, and the greatest epeirogenic movements of the past, determined by the thickness of the strata, amounted to a few tenths of a millimeter per year. Thus in the past the average rate of sinking of the most definitely negative areas was much smaller than the Recent rate in an area that we should at first sight be inclined to consider tectonically quiet.

In our estimates of rates of sinking in the past, we may be in error as to the duration of the periods of sinking, but there is reason

to suppose that our estimates of the lengths of periods are not ten times too high.

In our discussion of the apparent disproportion between the rate of sinking in the past and in the present, we must also notice that our estimates for the past involve very long periods, during which there is no reason to suppose that the rate was uniform. It was presumably now rapid, now slow, and perhaps for short intervals even reversed. The calculated average rates are thus derived from vastly different individuals rates, some very rapid, others very slow.

Compared with these averages, the high rate of Recent movements, even if we suppose it to have been uniform for the whole post-Pleistocene, refers only to a moment. Thus we can not deny that rates of sinking as high as the Recent rates may have occurred from time to time during past epeirogenic periods, and in this sense our Recent rates might be considered "normal" for those periods.

But there remains the other possibility, which I suggested in 1931, that we should compare what is happening to-day not with the non-orogenic periods of the past, but rather with the orogenic periods. In this case our Recent movements, however much they might resemble the epeirogenic movements of the past, would actually be "synorogenic," in the sense defined. We may now seek data on this problem in another region better adapted to furnish it.

V. EXCEPTIONAL POSITION OF PERI-PACIFIC REGION IN RECENT TECTONICS

Let us start again from the statement that during the orogenic periods of the past, the orogeny acted strongly (Alpine type) only zonally, in areas predisposed to such strong activity; that in other areas it acted weakly (German type) or in a nearly epeirogenic manner (synorogenic), or perhaps not at all. Speaking broadly, orogeny of Alpine type has become confined more and more to narrow belts of the earth's crust; that is, there has been an increasing degree of consolidation. In discussing the problem of whether or not orogeny is going on to-day, we should look primarily to those areas in which indications of relatively strong tectonic activity still exist.

Such areas surround the Pacific; and if we add to this peri-Pacific region the Malay Island region and perhaps its western continuation as far as the Ganges and the Himalaya Mountains, we may say that it includes nearly all those regions of the earth in which Recent tectonic activity seems to be especially intense. This province has four characteristics that are important from our present point of view.

1. The peri-Pacific-Malayan region is the seat of more than half of the world's earthquakes.

2. The borders of the Pacific and the adjacent Malayan district furnish the site for most of the vulcanism of the earth.

3. The peculiar morphologic phenomenon of deep-sea trenches—those long, narrow, deep, submarine furrows that are more than 7,000 meters deep, and in the extreme case of the Emden Deep 11,000 meters, and that parallel the margins of continents and island arcs—is confined to the peri-Pacific-Malayan region. For it should be noticed that the island arcs of the Antilles of Central America, and of the Southern Antilles south of South America, are merely eastward prolongations of the American peri-Pacific Cordilleran region. The only other truly great deep of our present oceans, the Romanche Deep of the central Atlantic Ocean, is in position and form a very different phenomenon.

The circle of deep-sea trenches is of course interrupted in many places in the peri-Pacific region, but these interruptions do not remove the possibility that the areas of interruption are also sinking; for of course we must distinguish the tectonic process, marginal *sinking*, and the morphologic feature, marginal *deep*. The deep will remain only if sedimentation fails to keep pace with sinking. Thus it is surely no accident that deeps remain only in regions where the drainage area contributing to them is small. It would nevertheless be going too far to say that absence of deeps is always due to filling by sediments; on the contrary we shall deal later with an area in which not only the morphologic deep but also the tectonic sinking seems to be absent.

The fact that any marginal deeps still remain unfilled proves that the sinking tendency still exists to-day.

4. A peculiar and characteristic gravimetric phenomenon is found along the peri-Pacific-Malayan borders. It is a narrow belt of negative anomalies lying between broader areas of positive anomalies, and is known to us chiefly from the submarine investigations of Vening-Meinesz. It is best known in the southwestern Pacific and in the Malayan and West Indian regions. From tests made at random in other areas it seems probable, however, that the phenomenon is a general one. It can only be attributed to Recent deep-seated magmatic movements that have concentrated relatively light magmatic masses in a narrow belt.

In these four respects, the peri-Pacific region is tectonically exceptional. If Recent orogenesis exists, we may say in advance that it is to be expected here rather than anywhere else.

Recent faults with horizontal and vertical displacements, are known from such peri-Pacific regions as Japan and California. In both of these earthquake-ridden regions, excellent facilities for observing earthquakes have long existed and have recorded the Recent movements of the crust.

Comparable with the conditions in Central Europe is what A. Imamura (1930) has called the "chronic" uplift and downwarping of the Japanese Islands. The warping in Central Europe amounts to several millimeters, however, while that of Japan amounts to several centimeters. The intensity of warping is thus on the average ten times as great in Japan as in Germany.

Besides these "chronic" movements there are also "acute" movements, in the sense of Imamura. These are the movements directly related to earthquakes. The amounts are of the order of several meters in either a horizontal or vertical direction.

VI. CALIFORNIA

For more thorough consideration we choose California, the part of the peri-Pacific region that is geologically the best known, "the land where the earth lives to-day, and we see the mountains grow" (H. Cloos, 1928).

I can speak of this land from my own experience, and in this connection wish to thank many fellow geologists of California's higher schools and oil fields, who guided me and assisted me during my studies in the summer of 1933. Of them I shall mention at present only Ralph D. Reed, whose critical volume, *Geology of California*, had just been published at that time. Together with the *Guidebooks* of the International Geological Congress, this book gave me an excellent introduction to my studies; furthermore, its author's geological interest and detailed knowledge gave me, during many conversations and on excursions lasting several days, the foundation for a study of numerous problems. My thanks are also due to my former student, Joseph S. Hollister, who accompanied and guided me on long journeys in the American West, and who, in his California home, was my faithful associate in the investigation of problems that we had pursued together in Europe at an earlier period.

To appreciate the Recent tectonics of California it is necessary to begin farther back and consider the events of the past.

PRE-PLEISTOCENE TECTONICS OF CALIFORNIA

The California Basement (*Nevadian*).—The late Cimmerian, or as it is commonly called in California, the Nevadian orogeny (Black-

welder, 1914, p. 644)[5] makes a sharp break in the geological history of California. It allows us to classify the rocks into a Basement complex, intensively folded (Alpine type), extensively intruded by batholiths and frequently metamorphosed; and a relatively much less folded post-Nevadian overlying series, the Sedimentary blanket. During the earliest geological investigations in California, which were naturally devoted to the gold-mining districts of the western Sierra Nevada, these divisions were recognized as the "Bed-Rock complex" with its gold veins, and the "Superjacent series." We have here the counterpart of the conditions in extra-Alpine Central Europe, except that in the latter case the great division between basement and blanket comes in the later Paleozoic. In its origin and appearance, however, as well as in its relation to later events, the Nevadian complex of Pacific America plays a part similar to that of the Variscan of Central Europe. Locally the Variscan orogeny affected western America, as in the western Sierra Nevada, but it is absent east of the Sierra Nevada in the district beyond Owens Valley. The Variscan orogeny therefore did not result in complete consolidation so as to exclude later folding of Alpine type, but served as a local initiation of the evolution of the Alpine-type folding that reached its culmination and conclusion over a large area during the Nevadian orogeny. In some regions, at any rate, we seem justified in calling the California basement "Varisco-Nevadian."

In many places the Nevadian orogeny acted asymmetrically, its movement being directed westward (that is, it is "west-vergent"),[6] as is shown, for example, in the Sierra Nevada region by the prevalent east dips of strata and of axial planes of anticlines and synclines, many of them isoclinal, and by the direction of over-thrusts. East-vergence seems to be exceptional (e.g., Taylorsville district); it is perhaps somewhat more common in the eastern part of the folded region. The foreland of the Nevadian orogeny seems accordingly to have been the Pacific region. Immediately after the folding there was a great intrusion of granodioritic plutonic rocks, a well known example being the Sierra Nevada batholith, the intrusion mechanics of which have

[5] Instead of "Nevadian" the term "Andean" is often used especially in publications written by others than American geologists. It rests on the assumption that the chief folding of the South American Andes—which are similar to the Sierra Nevada in many respects such as the occurrence of great batholiths—is contemporaneous with the folding of the North American Sierra Nevada. This idea is erroneous. The Andean folding was not pre-Cretaceous like the Nevadian but intra-Cretaceous. It belongs chiefly to the sub-Hercynian phase.

[6] The term "Vergenz," in English "vergence," has been introduced by Stille to express the apparent direction of tectonic movement in strongly folded or thrust-faulted regions. H. A.

been recently cleared up by Hans and Ernst Cloos, with the collaboration of Robert Balk. The work was done by the methods devised by Hans Cloos. Besides the continental area of California, the shelf region was also folded during the Nevadian orogeny, since the islands that rise above the broad continental shelf of Southern California have outcrops of granites and of folded sedimentary rocks that closely resemble those of the continent.

The Nevadian folding of western America took place in the area of a great geosyncline, the Alpine type of which is indicated by the great thickness of marine Triassic and Jurassic strata, and also by the ophiolitic extrusions and intrusions of these periods.

As to the exact date of the folding, the "Jura-Trias" Mariposa slates of the Sierra Nevada, with faunas as young as Kimmeridgian, are involved in the folding. On the other hand the Cretaceous lies unconformably on the folded series with its granites. The Lower Cretaceous, the Knoxville, carries a Portlandian fauna at its base (J. P. Smith), and thus the folding seems to be restricted to the interval between Kimmeridgian and Portlandian, and to correspond to the later Cimmerian orogeny of Europe. The stratigraphic relations of the basement are not everywhere entirely clear, particularly as to the exact age of the members of the "Franciscan," which is at least partly Jurassic. On this point reference may be made to a paper by C. H. Crickmay (1931).

FIG. 2.—Diagrammatic sketch to show relations of Nevadian basement and post-Nevadian sedimentary blanket.

The Nevadian folding acted far enough west to affect the shelf region of California, as already suggested, and died out toward the east in the midst of the Basin Ranges—that is, far to the east of California. In Oregon its effects seem to extend still farther east. East of the region with Nevadian folding lies the area of the younger Laramide folding, with dominant east-vergence.

The Nevadian folding extended from the California shelf to Nevada, a distance of 400–600 kilometers; a distance twice or thrice the width of the Alps. This fact illustrates the importance of this orogeny, which is sometimes undervalued in America. And yet in

California we are dealing with an orogeny of a single phase, while the Alps were produced by several orogenic phases.

The region of Nevadian folding is widely covered by younger deposits, it is true; but how great are the areas in Central Europe in which the Variscan is nowhere exposed, and yet nobody doubts that these regions were folded during the Variscan orogeny. Furthermore, the older events are often masked by younger ones, and the student is thus inclined to direct attention first to the results of the later folding and to underestimate the importance of the older, which happened earlier and is recorded in complex basement rocks hard to decipher. Wherever the basement can be studied in California, however, it furnishes clear indications of a strong pre-Cretaceous orogeny of truly Alpine type.

California in post-Nevadian time, before Pleistocene orogeny.—An entirely new chapter began in the history of California after the Nevadian orogeny. From that period the California region was no longer geosynclinal in the strict sense (orthogeosynclinal); no longer Alpine type; no longer, to use Bucher's expression, a "homogeneous mobile belt"; but it became a part of the American continental area and its later development was German type. It constitutes in part (Coast Ranges) a "heterogeneous mobile belt" in Bucher's terminology, in part (Sierra Nevada) "fracture belts of low mobility." Upon the great homogeneity and high mobility of pre-Nevadian time followed the heterogeneity and greater stability of the post-Nevadian.

With respect to the heterogeneity we may distinguish areas of two types, depending on the kind of Nevadian basement. If the basement consists of the Franciscan series, a certain degree of mobility is expressed in its later history; where it consists of granitic rocks and the sedimentary rocks metamorphosed by them, the basement shows a higher degree of rigidity. Areas of the former kind are found in the Coast Ranges of western California, but even here more stable belts with granitic basement (Salinas Valley region) are not entirely absent. Areas of the second kind are more common in the east, the most striking example being the Sierra Nevada block. Here we have an area that was scarcely folded in post-Nevadian time, but strongly affected by faulting; except in the marginal parts the sedimentary cover is very thin. If we were to use a German expression we should call this region "flachgründig" ("thin-blanketed" of G. D. Louderback, 1929). Its epeirogenic activities have affected relatively large units.

In contrast to the Sierra Nevada, we have farther west many "thick-blanketed" areas; and even the epeirogenic succession—to begin with it—has been complex. Immediately west of the Sierra

Nevada we have the strikingly deep basin of the Great Valley, lying between the Sierra Nevada and the Coast Ranges, and called San Joaquin Valley toward the south, Sacramento Valley toward the north. In the Coast Ranges, in particular, instead of the more uniform sedimentation of the earlier Alpine-type period we have complicated epeirogenic movements, with many local basins separated by belts that subsided less rapidly. Facies and thickness of sediments instruct us on this point, on the transgressions and regressions, and even on the displacements of the local basins that occurred during the tectonic evolution of the district. The Pacific Ocean transgressed repeatedly, continental sedimentation occurred at times, and occasionally there was a rapid alternation of marine and continental sedimentation. The thickness of sediments, especially in the middle of basins, is in some places enormous. From one of Reed's sketches (1933, Fig. 55, p. 275) we may infer, for example, that in the parageosyncline of Sacramento Valley the Cretaceo-Tertiary blanket reached a maximum thickness of more than 50,000 feet, which decreased rapidly east and west to 10,000 feet and less. Similar thicknesses are found in Ventura Basin in Southern California. In this basin, in fact, we have the thickest Tertiary section in America, "if not in the world" (Reed, p. 10), but only in a small basin, the margins of which sank much less. The existence of barriers (Schwellen) between the several basins are known not only from the thinning of the sediments and their wedging out, but also from the kind of material brought to the basins of sedimentation. On this point reference may be made to the derivation of Pliocene pebbles of the Los Angeles Basin from near-by highland areas with characteristic petrographic constituents (E. C. Edwards, 1934).

The post-Nevadian epeirogenic development of California parallels that of post-Variscan Central Europe, particularly in relation to the rising and sinking areas, as Bucher has suggested (1933). In the region of the Coast Ranges the intensity of the epeirogeny has been much greater, however, as shown by narrowness of basins and inter-basin barriers, and by amount of subsidence. Even the post-Variscan late Paleozoic of Central Europe, which is related to the Variscan main folding episode about as the California Cretaceous and Tertiary are related to the Nevadian orogeny, indicates similar epeirogenic intensity only locally, as in the Saar Basin.

In view of the vigor of epeirogeny as an expression of great tectonic energy, it is striking that the other expression of this energy, orogeny, seems to have slumbered during most of the time since the Nevadian folding. Yet we are dealing with a period that saw great mountains

arise in other parts of the world, some of them in America and not far away.[7] It almost seems that after the great Nevadian orogeny, the orogenic energy of California was exhausted for a long time.

An unconformity between Lower and Upper Cretaceous, corresponding to the Austrian folding of Europe, is often mentioned in American publications, and was named "Oregonian" by E. Blackwelder (1914); locally it certainly exists and is often accompanied by basic intrusions, but it does not seem to have importance anywhere.

Orogenic movements within the Upper Cretaceous, which are very important in other parts of the earth, such as South America, have not been recognized in Pacific North America.

The Laramide folding, which was very strong about the end of the Cretaceous in the Rocky Mountains, is locally recognizable in California by weak discordances. M. A. Hanna (1926–27) gives an example near San Diego.

Neither a Pyreneean orogeny (between Eocene and Oligocene) nor a Savic (between Oligocene and Miocene) seems to be well represented in California.

It is not till we reach the intra-Miocene disturbances, comparable to the Styrian foldings of Europe, that we have clear indications of folding in California. Even here, the more the occurrences are investigated, the more these "Antillean" disturbances (Blackwelder, 1914) seem to lose the significance that was formerly attributed to them. They furnish us, nevertheless, with the only Tertiary orogeny of which fairly strong indications exist in local areas in California. The disturbance had two phases, moreover, like the Styrian orogeny of Europe. Reference may be made, for example, to the unconformity at the base of the Middle Miocene in the Santa Monica Mountains[8] (Hoots, 1931, Plate 17), and to the one at the top of the Monterey in the Santa Cruz Mountains and in the Santa Ynez Mountains (R. Arnold, 1907); meanwhile the supposedly best example of the post-Monterey disturbance, that of the Salinas Valley, has come to seem less important than before (Reed, 1925; 1933, p. 206). In most localities, moreover, the Middle Miocene lies conformably between older and younger strata, and the younger Miocene beds are no less strongly deformed than the older Miocene, or the early Tertiary.

[7] In the following discussion I summarize very briefly the Cretaceo-Tertiary orogenic history of California. It is related to our theme since it helps explain the tectonic conditions at the beginning of the last orogeny. Details and more complete references will be given in the second edition of *Grundfragen der vergleichenden Tektonik*.

[8] The discordance mentioned occurs between the Modelo formation, Upper Miocene, and the Topanga, now referred to the Middle Miocene. In the San Joaquin Hills southeast of the Los Angeles Basin there is, however, an important unconformity between Middle and Lower Miocene. The author's contention that the intra-Miocene disturbance is a two-phase one in California is therefore correct. H. A.

Orogenic movements at the end of the Miocene (Attic phase) and also within the Pliocene (including Lower Pleistocene) were of slight importance and are often doubtful. "Post-Pliocene" and "pre-Pleistocene" foldings are often mentioned in the literature, but the age determinations are generally not precise, since the folding merely occurred at some period between Pliocene and late Pleistocene. In such cases, experience in other parts of California leads to the suggestion that the folding was really the intra-Pleistocene one to be described later, rather than the Wallachian.

We have thus seen that in the entire series of strata from Upper Jurassic (lowest Knoxville) to early Pleistocene, important unconformities are exceptional though a little more common in Middle and Upper Miocene. There are of course many "unconformities," developed, for example, as a result of epeirogenic uplift and resulting denudation, or of the epeirogenic shifting of the borders of sinking basins. Before we can speak of orogeny, however, we need the proof of structure-changes of the kind that produce strong angular discordances.

Block-faulting, of the kind that is commonly found in California, is also an orogenic movement; if it takes place vertically, moreover, without tilting the beds, angular discordances may fail to appear. Some movements of this kind may have begun in the Tertiary, or even in the Cretaceous,[9] and there may have been recurrent movements, particularly in orogenic periods.

A conception current in California for a long time, now vigorously defended by B. L. Clark (1930) and following him by W. H. Bucher (1933), seems to me to be extreme. It is that the diastrophism of the Coast Ranges consists entirely of continuous block-faulting and that the folding has been by comparison a secondary phenomenon. According to this conception, the basins and uplifted areas are not due to warping, but are differentially moving blocks ("anticlinal blocks," "synclinal blocks"). Against this idea Reed says (1933, p. 280) that at least the block theory has not been proved and that in fact the supposed proof has been greatly weakened in those areas, such as the oil regions, where detailed work has accumulated many new data. We face similar problems in Germany. The eastern border of the Rhenish massif, facing the Hessian basin, for example, has persisted since the Upper Permian, and is followed by faults. These facts do not mean

[9] Some faults are supposed to date from before the Cretaceous or even from before the Franciscan. The former is conceivable but the latter scarcely so, since the faults would have had to maintain their position during the strong Nevadian orogeny which crushed the entire geosynclinal area.

that the Hessian basin has been sinking along faults since the Upper Permian; in other words, it does not prove the block theory, as it is held by many California geologists. This German example shows, on the contrary, that the marginal faults of the Rhenish massif either came into existence during orogenic periods after the sinking of the Hessian basin, or, perhaps, during orogenic periods that interrupted the subsidence. It seems to me quite possible to explain the California conditions in accordance with the ideas gained from the German "Saxon-type" conditions, and thus to reach a conception of the tectonic evolution similar to that suggested by Reed (Fig. 10, a and b, p. 55) in a diagrammatic section through the San Joaquin Basin (Coalinga anticline, et cetera).

PLEISTOCENE OROGENY OF CALIFORNIA

Culmination of Pleistocene orogeny.—Cretaceous and Tertiary together may have lasted more than 100 million years, and for this long period we know in California only relatively modest orogenic interruptions. Only in the Pleistocene does a really strong orogeny appear. The general lack of orogenic activity during the time between the Nevadian and this Pleistocene folding is best shown by the fact that in many localities the folds and faults of the younger Tertiary and even of the Lower Pleistocene are nearly as strong as those of the older Tertiary and Cretaceous (Reed, p. 262).

It is a surprising sight to see, near Los Angeles, thick beds now referred to the Lower Pleistocene, lying concordantly on similar Pliocene beds, and all of them strongly tilted, overturned, and even overthrust by older rocks. From the disturbance of the bedding the German geologist is reminded of the well-known zone of overthrusting along the north border of the Harz, or of the depressed and overturned and overthrust Saxon anticlines—except that the beds in question here are so extraordinarily young!

The folding period under consideration was recognized as Pleistocene very early (Lawson, 1893), but later was often placed at the boundary of Pliocene and Pleistocene ("Santa Barbara orogeny of Blackwelder; see also Blackwelder, 1912, pp. 66, 200), and thus seemed to correspond to the Wallachian phase of my proposed list of Tertiary orogenies (1924). B. L. Clark, in 1930, also lets the "Coast Range revolution" begin toward the end of the Pliocene, though he refers its main act to the Pleistocene. I wish to call this young orogeny by a new, unburdened term, and therefore propose "Pasadenan," after the city so well known in the world of Natural Science, near which the extreme youth of this orogeny is so clearly perceived. I

wish the term "Pasadenan" to cover also all Pleistocene orogenic phases the world over.

In the Los Angeles region, to which Pasadena belongs, the San Pedro Hills have been the classic locality for study of the marine Pleistocene and its structure ever since the appearance of Arnold's monograph (1903). Here the Pasadenan folding affected three Lower Pleistocene formations named, from oldest to youngest, Las Posas, Timms Point, and lower San Pedro (San Pedro sand). Considerably younger than the folding, or at least than its culmination, is the likewise marine upper San Pedro (Palos Verdes). It has a moderately warm-water fauna (J. P. Smith, 1916); that is, it seems to belong to an interglacial stage. In the opinion of W. P. Woodring (1933) and others, it belongs to the last interglacial stage. In contrast, the lower San Pedro fauna indicates a cooler climate. In the pre-Pasadenan Pleistocene, in fact, the faunas suggest a recurrence of cooler and warmer water (H. S. Gale, 1932, p. 8), but W. P. Woodring (*op. cit.* p. 36) considers the possibility that they express varying depths of water and other ecologic factors. He would refer the folding visible in the San Pedro Hills approximately to the Middle Pleistocene. A similar view is taken by H. R. Gale (cf. Reed, 1933, p. 268), who places the San Pedro in the Third Interglacial stage (Sangamon Interglacial stage of eastern United States, correlated with the Riss-Wurm Interglacial stage of Penck and Bruckner; cf. Woldstedt, 1929, Plate II), and the deformation in the time of the Second Interglacial stage (Yarmouth, or Mindel-Riss). Thus according to Gale (1932), the great Pleistocene revolution can not be dated "before the Middle Pleistocene."

Though the stratigraphy of the older Pleistocene and younger Pliocene is not clear in all respects, it is generally admitted, as Reed states (1933, p. 256), that in the Ventura Basin, for example, some hundreds or even thousands of feet of marine Pleistocene strata have been involved in the folding.

We have to consider the Pasadenan folds as belonging to the class of "frame-folding," in so far as they were produced in relatively restricted basins surrounded by "frames," and are dependent upon these more rigid masses for their position, direction, and strength. They are accompanied by faults, many of them reverse, passing into flat overthrusts; near the faults the beds are commonly overturned. The direction of the thrusts and the vergence of the orogeny are generally westward or southward. This direction is conditioned by the previous epeirogeny, however, and thus the opposite vergence may be found. The same uplifted area may be overthrust

in opposite directions at its margins, as happens, for example, in the case of the San Bernardino Mountains.[10]

The relations between the nature of the orogenic action and the kind of basement are as evident in the post-Nevadian, chiefly Pasadenan orogeny of California, as in Central Europe. The relations are shown in two profiles[11] that G. D. Louderback (1929) has published to illustrate this important fact. The first shows a very thick-blanketed region with strong folding and local thrusting. The second illustrates a thin-blanketed area, with many faults and some thrusts, located in the Santa Lucia Mountains south of Monterey (Trask, 1926).

The younger folding of California shows a dominant north-northwest strike, but there is also an east-west trend in a narrow belt that reaches the ocean at Los Angeles and Santa Barbara and continues into the islands of the continental shelf. This belt constitutes the "Transverse Ranges" of R. T. Hill and R. D. Reed, the "Los Angeles Ranges" of F. L. Ransome. To it belong the San Bernardino Mountains on the margin of the Mohave Desert, the San Gabriel Mountains and Santa Monica Mountains north of Los Angeles, and the Santa Ynez Mountains near Santa Barbara. They all acquired their chief orogenic features during the Pasadenan disturbance. An example of a north-northwest-striking Pasadenan fold, involving Lower Pleistocene strata, is found in the greatest oil-bearing anticline of California, the Kettleman Hills anticline[12] in the San Joaquin Valley. Other examples of young folds and thrusts long recognized as of post-Pliocene age (Lawson, 1893) are found on the San Francisco Peninsula and near Mount Diablo.

The folds, often very intense, and the overthrusts accompanying them, are the result of crustal compression combined with shearing stresses. Shearing faults have become overthrusts in the course of the compression.

Besides the areas affected by Pasadenan folding, there are the thin-blanketed areas in which faults are very important while folding is weak or even absent. It seems reasonable to date many of the faults as post-Tertiary since post-Tertiary orogenic movements are known in so many places. Furthermore, the relatively small importance of post-Nevadian pre-Pleistocene orogenic activity leads to the suggestion that it may also have been unimportant with respect to the great

[10] On the northward thrust at the northern margin of the San Bernardino Mountains see the fine description of A. O. Woodford and T. F. Harriss (1928, Pl. 40).

[11] They are reproduced by Reed, 1933, Figs 13 and 14.

[12] See for instance the fine view of the Kettleman Hills, taken by The Texas Company and reproduced by Gester and Galloway, 1933, Fig. 5. The uppermost beds, which participated in the folding along with the Tertiary, are of Lower Pleistocene age.

block-movements of California. The conception of a dominantly Pleistocene age for the fault system of California and the Basin Ranges has been widespread in California since the time of J. Le Conte (1895).

Continued investigations may give a more accurate date for the main act of the Pasadenan folding than we can give to-day. If so, we shall be able to answer more definitely the question as to exactly how long ago the orogeny took place, but we can make a fair preliminary estimate to-day.

According to present knowledge, we may set 500,000–600,000 years as the probable length of the Pleistocene.

We must next consider two matters.

First, before the beginning of the orogeny Pleistocene sediments were deposited to a thickness of hundreds, or even thousands of meters. Even with a rapid rate of sinking, their deposition must have required a considerable time.

Second, since the culmination of the orogeny, there has been enormous denudation locally. If, for example, the Lower Tertiary appears on the axis of an anticline, and if the sedimentation lasted till the time of the Pasadenan orogeny, and if the Tertiary section is without important unconformities, then it is obvious that all of the younger Tertiary strata must have been eroded from the axis of the anticline since the orogeny. For the Kettleman Hills, the denudation amounts to 1,000 meters, as Reed suggested; for the Ventura Basin, J. E. Eaton (1928, p. 136) gives the amount of the post-Pasadenan denudation as 5,000 feet. Erosion may have gone on rapidly because of supposedly strong relief and the dominantly soft nature of Tertiary and Pleistocene material, but even so a long time must have been needed.

All things considered, it is clear that both before and after the culmination of the Pasadenan orogeny events took place that required a long time, though exactly how long can not be known. From such considerations it seems that we may not be far wrong if we assume that the orogeny occurred approximately in the middle of the Pleistocene, as the stratigraphic data also suggest (p. 206). If so, it may have taken place 250,000–300,000 years ago.

The post-Nevadian, chiefly Pasadenan, orogenesis is German type; that is, it offers something new with respect to the Alpine-type Nevadian folding, and acted in an area completely changed by the latter. It fails to be a continuation of the Nevadian folding, just as the Saxon folding of Central Europe fails to continue the Variscan even though an occasional feature of the latter may recall something that preceded it. It is thus not possible, even in the Coast Ranges—though it has been attempted—to compare the post-Nevadian orogeny of California with Alpine folding. Similarities with Alpine conditions exist

in California only until the Nevadian orogeny, just as they exist in Central Europe only until the Variscan. The California Tertiary deposits are sometimes stated to be foredeep deposits, like the Molasse, but their deposition in relatively confined basins that are interrupted by barriers ("Schwellen") speaks against this idea. If the Nevadian orogeny really had a sub-Nevadian foredeep, like the ("sub-Alpine") Molasse basin of the Alps, or the "sub-Variscan" foredeeps of Central Europe and of the Appalachians, into which the folding migrated during later periods, the position suggested for it by the west vergence of the Nevadian folding would be west beyond the shelf region, since as we have seen, the shelf was folded. A sub-Nevadian area beyond the shelf, and thus beyond the continental area under the deep sea, is a concept difficult of belief. Thus we may take it as fairly certain that the California continental area was not enlarged in post-Nevadian time.

Farther north in Oregon and Washington, the Tertiary is not a sub-Nevadian series, deposited upon a previously unfolded basement, but, as the Nevadian structures of such areas as the Olympic Mountains indicate, it is rather a deposit in an intra-Nevadian basin, the parageosyncline of the Puget trough, comparable to the Great Valley; and it is of course not Alpine type, but German type, though locally stronger.

Tectonic events after culmination of Pleistocene orogeny.—Pleistocene strata younger than the strongest Pasadenan folding are commonly not inconsiderably folded. At San Pedro near Los Angeles I was able to convince myself of this fact under the guidance of R. D. Reed. In a canyon near Walteria, the Palos Verdes formation, resting with a basal conglomerate on steeply tilted older Pleistocene, is itself inclined at an angle as great as 20°. Woodring mentions (1933, p. 38) dips of 26° from this same region. Very young dome-like tectonic uplifts, such as Dominguez Hill and Signal Hill, occur in the Los Angeles Basin along a northwest-striking anticlinal axis. H. Cloos mentioned their *en échelon* arrangement in 1928. They are recognizable topographically as low uplifts, a fact that indicates the extreme youth of the warping. On the flanks of Signal Hill the Upper Pleistocene dips as much as 25°. That these topographic elevations are in general underlain by tectonic anticlines is confirmed by borings, some of which have discovered rich oil accumulations. In fact, these recent uplifts have been used as guides in the search for new oil fields. In Dominguez Hill the gradual uplift is proved (F. P. Vickery, 1927) by an antecedent stream that cuts across the hill. Similar conditions, suggesting posthumous warping on the site of underlying anticlines, have been successfully used in searching for oil.

Faults that have moved since the Pasadenan folding may be seen in many places. A striking example, along which the Miocene Monterey formation lies on Upper Pleistocene, has been described by Reed (*op. cit.*, p. 57) from the vicinity of Santa Barbara.

In the southeastern part of the course of the famous San Andreas fault, well known from its connection with the San Francisco earthquake of 1906, I was shown very recent horizontal displacements exceptionally well indicated by the lateral deflection of small stream courses. Under Louderback's guidance, I saw near the University of California very similar features along the Hayward fault (cf. Buwalda, 1929), an easterly branch of the San Andreas. The very recent horizontal displacement here amounts to several hundred meters. A. C. Lawson and P. Beyerly had the kindness to show me, at Sausalito north of San Francisco, a place where horizontal displacement is known to have occurred in connection with the earthquake of 1906. I also visited the famous young fault scarp along the east flank of the Sierra Nevada in Owens Valley, and its counterpart east of the Great Basin along the west flank of the Wasatch Mountains. Everywhere one receives the impression that the German-type orogenic structure of California is still developing to-day, both in warpings that are so sharp as to come under the class of folds, and—this point is especially striking—in vertical and horizontal movements along fault systems.

Horizontal movements have received much attention in California, largely because of their importance during the San Francisco earthquake of 1906. According to the expositions of H. F. Reid (1910), A. C. Lawson (1921), and others, they are associated with deep, horizontally directed, magmatic movements—a plausible hypothesis. If so, the deep movements might be orogenic—a part of the great material displacements that accompany orogenesis. Even in Saxonian Central Europe, according to the results of F. Lotze (1932) and others, some important features can be satisfactorily explained only on the hypothesis of horizontal displacement of great blocks; but the manifestations of this drift, as an integral part of Saxon-type tectonics, follow the orogenic time law. From this fact the conclusion is natural that even this movement of great blocks is episodic, and thus orogenic, as is the more fundamental phenomenon to which it is related. In this connection we may think, too, of the processes of the magmatic zone that seem to find expression in the peri-Pacific-Malayan belt of negative gravity anomalies, and that are related in some way to the declining stages of the peri-Pacific orogenesis.

Even if recent horizontal displacements are of considerable im-

portance in California, still much of what has been written about them, and especially what has been written under the inspiration of the events of 1906 about their present magnitude, is not entirely valid; and thus, much water must be poured into the wine of enthusiasm concerning the mountain-building supposed to be going on before our eyes. Even at Sausalito, the classical site of the horizontal displacements of 1906, the expected continuation of movement, though often stated in the literature to be under way, is shown by geodetic measurements of fixed points not to have occurred.

The supposed recent northwestward drift along the west side of the San Andreas fault, assumed to be a result of "persistent northerly subcrustal flow," seems to be disproved by the comparison of older and newer precise triangulations made by the United States Coast and Geodetic Survey, as Bowie (1928) has shown. In general, there has been no displacement of triangulation points between the two surveys in central and southern California, except in places less than 20 miles distant from the San Andreas fault. W. H. Bucher (*op. cit.*, p. 317) has summarized the special literature on the subject, and closes his summary with the remark that the facts

> must be disappointing to those who have seen in California "indisputable" evidence of momentous subcrustal flows dominating the structural plan of the earth's crust.

VII. RECENT TECTONIC EVENTS IN THEIR BEARING ON QUESTION OF PRESENT TECTONIC STATE OF EARTH

From the foregoing discussion it might be possible to maintain that the Pasadenan orogeny is not yet completely finished, but the fact must not be overlooked that the folding had a culmination which it reached very early. The later crustal warpings are very small in comparison with the vigorous movements that strongly folded and fractured the Cretaceous, Tertiary, and Lower Pleistocene strata, and locally overturned them.

In still other cases we may reach the conception of a relatively early culmination of an orogenic period, that may nevertheless have been weak at the outset. In America, for example, we may think of the early strong folding of the Nevadian, producing isoclinal folds over great areas; later came the batholithic invasion; but the orogenic stress was then so weak that the granite rarely became gneissic, and remained dominantly normal and structureless. The whole disturbance constitutes the Nevadian orogeny, divided into an early culmination and a later decline. In other cases the magma was involved in the culmination of the folding and changed to orthogneisses, mixed gneisses,

or injection gneisses. During the same orogeny normal granite may form later after the compressive stresses weaken. Examples are known from the classic region of gneisses, the Erzgebirge.

If in the light of these examples from earlier periods we think of all the events that may follow one another during an orogenic phase, the idea does not surprise us that an orogeny that began only 250,000–300,000 years ago and reached an early culmination is not yet entirely concluded. But—one may ask—is not that which happened between Lower Pleistocene and Palos Verdes time the whole orogeny, which was thus extremely short-lived? And is not what followed epeirogenic, in the sense that it is comparable with the events of the long, "normal" periods of the past? And may not our conceptions of those normal times be incorrect if we suppose that they were too non-orogenic to admit processes like the Recent California examples? To assist in answering these questions we may imagine that the Los Angeles-Santa Barbara region has sunk beneath the sea—as its western continuation has actually done—and imagine the present structural features covered by horizontal strata. We may imagine, too, that after subsequent uplift the thinking beings of the Quintary epoch have the opportunity of investigating the structure. Would they not find, between the post-Pasadenan Pleistocene beds and those deposited after the submergence, angular discordances such as we do not know in the whole world for periods described as non-orogenic?

Furthermore: is it at all surprising that a genuine orogeny such as the Pasadenan should last throughout a period of 250,000–300,000 years, if we consider, as previously, the succession of events that has taken place during earlier orogenies?

A duration of 250,000–300,000 years for its whole series of events does not destroy the relatively "short-lived" character of an orogeny. In Chapter I it was shown that we know to-day more than 40 orogenies from the history of the past, but that only a few of them are of the first order as determined from the magnitude of their extent or their local intensity. In the list are included orogenies that are not yet known to have been important anywhere, and are not known at all over a great part of the earth. In the provisional arrangement of orogenies into four classes of intensity, the Pasadenan (Fig. 1), in consideration of its importance in western America and elsewhere, seems to belong approximately at the boundary of classes 2 and 3. If we assume, further, that there is a correlation between the duration of an orogeny and its local intensity and regional distribution, we might conclude that the time estimated for the duration of the Pasadenan orogeny is an average figure for the duration of other orogenies. Thus

we come to the conclusion that all post-Cambrian orogenic periods have occupied a total of 15 million years—assuming that future investigations will discover 10 orogenies that are still unknown. But if we assume that post-Cambrian time is 600 million years, the 15 million devoted to orogenic events constitutes only $\frac{1}{40}$. I do not believe that anyone can deny the term "short-lived" to events that take only $\frac{1}{40}$ the time of the other events with which they are compared. This "short-lived" character is well shown in the true-scale diagram (Fig. 1); the width of line is actually exaggerated in the figure, in order to make the lines visible.

And it should be noted that only a fraction of an orogenic episode is represented by the culmination, the greater part representing the declining stages. The Pasadenan conditions as well as those of other orogenies show this. And a part of the time may be given over to the introductory stages. How short, then, must the time of the culmination be!

Figure 1 shows a greater concentration of orogenies in younger Alpidic time, as compared with earlier eras. This condition can not be referred wholly or even chiefly to our more detailed knowledge of the conditions of the Alpidic era. The Variscan series is also so easily accessible and so thoroughly studied that we can not expect any important surprises in the form of discoveries of orogenies unknown to-day. It seems that the Variscan orogenesis, more intense and more widespread than the Alpidic, concentrated its energy into fewer phases than the regionally limited Alpidic orogenesis. The Pasadenan orogeny belongs to the Alpidic cycle, being (for the present) its last phase.

We had to go to the peri-Pacific region in order to reach a conception of the true tectonic nature of Recent time; and what we have seen in California gives a new aspect to the crustal movements of Central Europe (cf. Chapter III). We need no longer explain these movements as due to a speeding-up of a normal non-orogenic period. These rapid uplifts and sinkings, warpings and faultings, are synorogenic, and the rate of movement is thus abnormally high.

Whether we are to say that we live in an orogenic period, or, more conservatively, that such a period lies just behind us and still influences some geologic processes, in any event we can not use what is happening to-day as a measure of what has happened in non-orogenic —"normal"—times of the earth's history. Uniformitarianism, as the method of explaining what has happened in the past by reference to what is happening now, is valid for most of the events of the past, including the evolution of organisms. In its tectonic aspect, however,

the present illustrates not the normal, but the abnormal conditions of the past—that is, a catastrophic period in its decline.

The Pasadenan folding has German-type features in California. Does it have Alpine-type features, or at least strong Alpine-type suggestions, in other parts of the earth? The answer to this question leads us first to the phenomenon of foredeeps—that is, the oceanic deeps.

We have noticed the surprising fact (p. 871) that the Alpine-type Nevadian zone of folding, in its north-northwest course from Lower California to the border of Alaska, lacks the characteristic Alpine-type feature of a foredeep. The explanation can not be that the foreland was submarine, since the same is true of other parts of the Pacific border where oceanic deeps exist as representative of foredeeps; it is true also of the European Variscan region, insofar as it is not bordered, as in the north, by a rising positive area, but, as in its Atlantic portion, by the Atlantic Ocean (Stille, 1934). If a foredeep was absent from the Pacific shores of the United States and British Columbia regions even in the Tertiary, it is not surprising that oceanic deeps are also absent there to-day.

In a great part of the peri-Pacific-Malayan region, the foredeeps exist. They are even found in the Alaska region, in fact, beyond the point where the north-northwest trend of the folds and of the seacoast suffers a 90° change of direction. In those areas we might expect young Alpine-type tectonics, if we regard the Recent oceanic deeps as a particular variety of foredeep of our Alpine-type mountain system. The outer border of the South Asiatic fold region, surrounded with oceanic deeps in the Malayan region, continues with foredeeps to the southern border of the Himalayas and of the Iranian Ranges. Folds of extreme youth extend from Sumatra to the outer part of the Burma arc, the Himalayan system and the Iranian arc, as far as Mesopotamia. There, it is true, the folding is referred to the end of the Pliocene, since folded strata are called Pliocene and unfolded ones Pleistocene. It is not demonstrated faunally, however (Wadia, 1932; De Terra, 1933), that at least in the folded Siwalik series of the Himalayan border zone, the folding occurred in the Pleistocene. We may also assume an age lasting into the Pleistocene for the Bakhtyari series of the South Persian folded area, since it is considered contemporaneous with the Siwalik beds. In many places, as in the Punjab, orogenic movements are active today (J. M. Weller, 1928).

The investigation of fossil foredeeps shows that they follow in time the folding of the great mountains that they border. This is not to say that earlier sinking may not have occurred in the areas of the foredeeps, as, for example, in that of the sub-Variscan foredeep of

Central Europe, or the Appalachian of North America; but that a previously sinking area received a new impulse, characterizing it as foredeep development (Stille, 1929). In this sense, the foredeeps are features that develop post-orogenically, or between orogenic phases, and have thus their main development in non-orogenic periods.

The fact that they pass through orogenic periods undisturbed, as the present foredeep of the Alps passed through the Savic and Styrian phases, shows that a part of their development takes place during orogenic periods. The same is true of the Pacific, on the basis of our explanation of the present tectonic state of the earth.

I was at first inclined to the opinion, and am essentially so still, that sedimentation is not very rapid during orogenic times, particularly in regions of strong orogenic movements where orogenic uplift ordinarily leads to denudation; but upon the hypothesis that orogenic periods, including their declining stages, last a fairly long time, there is a possibility of thicker synorogenic deposits. We need only recall that in many regions thick strata representing a considerable part of the Pleistocene must now be considered synorogenic. From the same considerations we learn that two angular discordances separated by relatively thin strata may represent not two separate orogenic phases or "sub-phases," but may belong to the same one, in the course of which sedimentation was going on. The intervening strata should, of course, represent only a very short stratigraphic interval. In this connection, it would be important if we could determine the duration of an orogeny by studying the relations in a system that could be closely zoned, as by ammonites. We should presumably need to make such investigations in areas of weak, chiefly synorogenic movements. In the case of stronger orogenies, the stratigraphic interruption is likely to be due, not to the orogeny itself, but to the time required for eroding and resubmerging the orogenically uplifted area.

If on the basis of our tectonic interpretation of the Recent period, the term "synorogenic" is appropriate for the sedimentation of an orogenic phase, only a part of the sediments currently designated in the literature as "synorogenic" should be so called—not even all of the Alpine Molasse. It consists of rocks deposited as they have been because of orogenesis, but only in the sense that they were deposited in the foredeeps surrounding an orogenically uplifted mountain region. They are not in the main synorogenic, but post-orogenic—that is, epeirogenic. The boulder beds within the Molasse, if not due to atectonic conditions, may be due to occasional increases in the rate of epeirogenic uplift of the rising areas; only to a small degree do they reflect the orogenic conditions that occurred at the time of formation

of the foredeep. Thus only a small part of the Molasse is synorogenic in the proper sense of the word; in the case of the Alps, indeed, only that part which was deposited exactly at the time of the Savic or Styrian orogeny.

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GEOLOGY AND BITUMENS OF THE DEAD SEA AREA, PALESTINE AND TRANSJORDAN[1]

FREDERICK G. CLAPP[2]
New York, N. Y.

ABSTRACT

The Dead Sea (in ancient times called "Lake Asphaltites"), on the border between Palestine and Transjordan, lies in a topographic depression of which the water level is 1,292 feet below the Mediterranean Sea and the altitude of the surrounding land averages between 1,500 and 3,500 feet. The depression, including the Valley of the Jordan and the southern "Ghor," forms a "ramp" type of graben between more or less complex bounding faults.

From a geologic standpoint the most abnormal feature of this graben is Jebel Usdum—a salt dome of which the crest lies 742 feet above Dead Sea level and thereby attains a position 550 feet below the Mediterranean. El Lisen Peninsula is another land mass, standing only a few score feet above the water, but dividing the "lake" into a deep northern and shallow southern area. Sub-sea depths in the northern portion descend nearly 2,900 feet below ocean level. It is beneath the southern bay that the sites of the legendary settlements of Sodom and Gomorrah are supposed to lie. Oil and bitumen exudations, authentically reported throughout the Dead Sea area and best observed in a ravine behind Jebel Usdum, may or may not indicate the presence of important oil deposits, but some indications of suitable structure exist. At any rate, archaeology and geology unite with seepages to confirm the Biblical account of Sodom's destruction.

INTRODUCTION

The subject of this discussion—formerly known as "Lake Asphaltites"—is an earth feature famous in sacred history, referred to by historians for over two thousand years and a subject of geologic controversy over the past century. Reclus[3] considered it "the most curious" of all inland seas. It has already received scientific attention, for the general geology was described by Blake,[4] Government geological adviser, and previously by Blanckenhorn.[5]

The third volume of de Luynes' monumental work[6] is given up to a treatise on the geology of the Dead Sea by Lartet with a large geologic map, fossil sections (Plates 1 and 2) and plates of forms.[7] The maps,

[1] Manuscript received, March 20, 1936.

[2] Consulting geologist, 50 Church Street.

[3] Élisée Reclus, *The Earth*, New York (1871), 567 pp. p. 407.

[4] G. S. Blake, *Geology and Water Resources of Palestine*, Jerusalem (1928), 51 pp.

[5] Max Blanckenhorn, *Naturwissenschaftliche Studien am Toten Meer und in Jordantal*, Berlin (1912), 478 pp.

[6] H. T. P. J. d'A. le Duc de Luynes, *Voyage d'Exploration à la Mer Monte, à Petra et sur la Rive Gauche du Jourdain*, Paris (1874), 4 vols.

[7] L. Lartet, *op. cit.*, Vol. III, 326 pp.

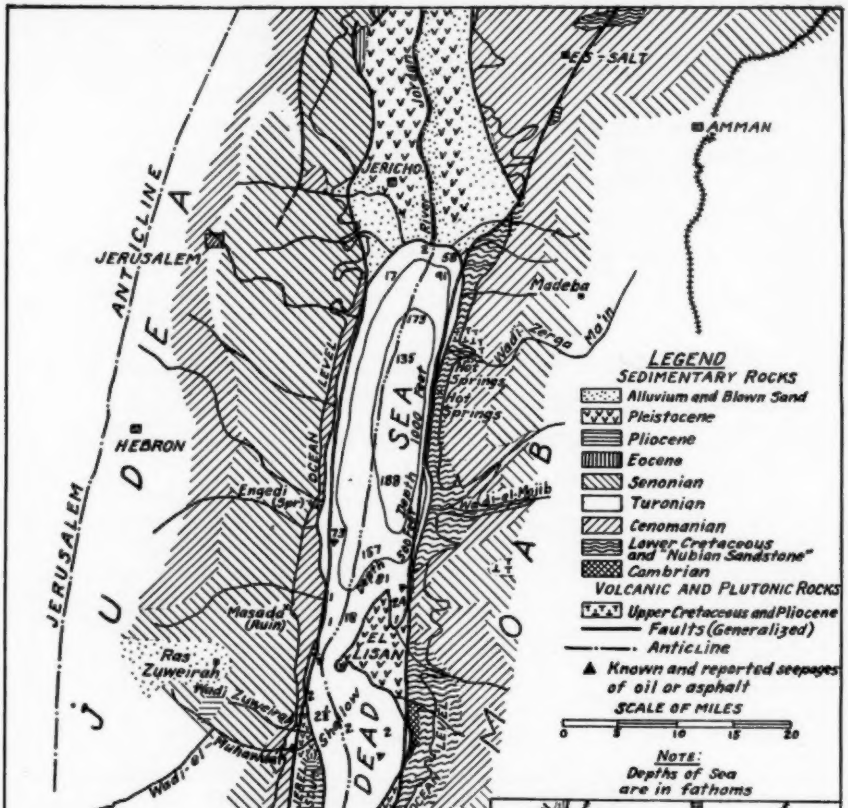

FIG. 1.—Geologic sketch map of Dead Sea area.

although seriously out of date and without age or subdivisional criteria, give such detail as was possible on his scale of 1:300,000 and a fairly thorough reconnaissance of the coast and highlands. More recently Willis[8] gave an exposition on the mechanics of the valley in which this lake is situated. In 1921 Arthur Wade[9] published a cross section from the Judean highlands to central Transjordan, calling attention to the existence of oil and asphalt seepages and bituminous impregnations in rocks of Cretaceous age. Fohs[10] has discussed petroleum geology of the entire Palestine nation, and a few other writers have touched on various phases of the Dead Sea and Jordan Valley. Nevertheless a brief exposition of the lake[11] as a structural unit may be helpful in the appreciation of graben problems.

TOPOGRAPHIC ASPECTS OF DEAD SEA AREA

The physical aspects of the Dead Sea are as unique as those of any body of water in the world. This lake, the surface of which stands 393 meters (1,292 feet) and the greatest abyss 875 meters (2,882 feet) below Mediterranean level, lies in a north-south graben, variously called a *rift* or *ramp* valley, 360 kilometers (225 miles) long, extending with variable development from Lake Tiberias south to the junction of the Gulf of Akaba and the Red Sea.

As early as 1837, G. H. Moore and W. G. Beek[12] announced that the Dead Sea "appears to be considerably lower than the ocean." The breadth of this depression, formed in Pliocene and Recent times, ranges from 13 kilometers (8 miles) near the head of the Dead Sea to 26 kilometers (16 miles) at Jericho. A strong topographic relief lends interest to the drive from Jerusalem to the head of the Dead Sea, 10 kilometers (6 miles) south of Jericho, along which the highway descends approximately 1,200 meters (4,000 feet) in altitude. Hilltops in the vicinity of Jerusalem, Hebron, Amman and Kerek, which stand 750–1,150 meters (or 2,500–3,800 feet) above the Mediterranean Sea, form a dissected plateau level truncating the Jerusalem, Es Salt, and other anticlines. Yet deep gorges, miles in length, intersect this plateau, and the Arnon (Wadi el-Mojib), Zerqa Ma'in, and a few other small streams flow between vertical walls. Plentiful supplies of fresh

[8] Bailey Willis, "Dead Sea Problem: Rift Valley or Ramp Valley," *Bull. Geol. Soc. America*, Vol. 39 (1928), pp. 490–542.

[9] Arthur Wade, "Oil Prospects in Palestine," *Oil News* (June 11, 1921), pp. 584–86.

[10] Julius Fohs, "Geology and the Petroleum and Natural Gas Possibilities of Palestine and Sinaitic Peninsula," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 35–49.

[11] In this paper the terms "the Dead Sea" and "the lake" are used interchangeably.

[12] G. H. Moore and W. G. Beek, "On the Dead Sea and Some Positions in Syria," *Jour. Roy. Geog. Soc.*, Vol. 7 (1837), p. 456.

water are carried by several streams; and Zerqa Ma'in is warm where it enters the Dead Sea, owing to Hamman ez-Zerqa (Zerqa Hot Springs or "baths"), 5 kilometers (3 miles) upstream.

Near the south end, the continuity of the lake is half broken by a peninsula—El Lisan, rising 20–50 meters (60–160 feet) above water level—politically and geographically belonging to the kingdom of Transjordan. The land surface of El Lisan appears to be of Pliocene and more recent ages. South of this interruption very systematic soundings made by Lynch[13] proved the water to be only 2–6 meters deep (6–18 feet), on which circumstance we base a possibility that the embayment may have been land until early historical time.

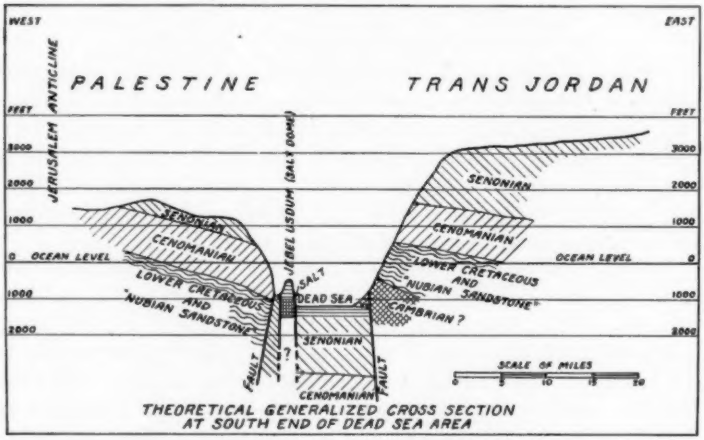

FIG. 2.—Generalized cross section near south end of Dead Sea.

In studying an east-west cross section near the south end of the lake, one is impressed by the sharp drop which takes place from the Kornub and Ras Zuweira plains, at altitudes of 600 meters (about 2,000 feet) and 630 meters (or 2,100 feet), respectively, down to water level at minus 393 meters (1,292 feet). Similarly the Transjordan topography descends from plus 950 meters (nearly 3,200 feet) to minus 360 meters (1,214 feet) in passing from Kerek to the uppermost surface of El Lisan.

Although mountain walls rise abruptly 700–1,100 meters (approximately, 2,400–3,700 feet) on the east side and 500–950 meters

[13] W. F. Lynch, *Narrative of the United States Expedition to the River Jordan and the Dead Sea*, Philadelphia (1849).

(approximately 1,600–3,100 feet) on the west side, such is not true at the north and south ends of the Dead Sea. The Jordan River, descending from 202 meters (666 feet) below ocean level at Lake Tiberias (Sea of Galilee) to 393 meters (1,292 feet) below ocean level at the Dead Sea, flows in a U-shaped valley, containing clay and sandy hills which are in places as much as 100 meters (or 330 feet) above river level, yet the land immediately surrounding the mouth of Jordan is comparatively flat. The "Ghor" is the name given to this valley stretch of 105 kilometers (65 miles) south from Lake Tiberias.

Modern writers occasionally include the "Southern Ghor"—the graben area south of the Dead Sea—as part of the Jordan Valley, and Old Testament chroniclers may have been in a similar habit. This "Southern Ghor" is, in wet weather, impassable, and considerable areas consist of swampy and drowned land where trunks of dead trees, long dead, still stand erect. The southern extension of the Southern Ghor is Wadi 'Arabah, formerly part of the "Wilderness of Zin"—important in Israelitish history.

CHANGES IN WATER LEVEL

Changes in water level are important in any consideration of the Dead Sea—whether historic, archaeologic or geologic. The level has not been constant, with reference to its banks, even during historic time, but lies about 2 meters (6 feet) higher[14] than at the time of an early survey, and the southern basin (south of El Lisan) is fully a third larger than it was a century ago. Albright states[15] that an outstanding fact is the steady rise of Dead Sea waters, due first, to deposits of silt at the mouths of the Jordan and other tributary streams, and secondly, to steady precipitation of mineral salts from a saturated solution—one and one-sixth times as heavy as pure water. Albright admits that the denudation of forest probably increased influx of water slightly, but he considers this a subsidiary cause. Blanckenhorn[16] tells us that a road along the base of Jebel Usdum (hill at the southern end of the lake) was 80–230 meters (approximately, 200–650 feet) wide in 1851, but has been under water since the early nineties. A forest of dead tamarisk trees standing in the water at the south end of the lake is proof of this rise of water.

[14] Schroetter, in *Das Tote Meer*, Vienna and Leipzig (1924), p. 12, gives the change in level as 4 meters in a century, but Masterman, who made measurements at Râs-el-Feshah (*Palestine Exploration Fund Quarterly Statement*, pp. 192 *et seq.*) found a variation of 60–90 centimeters annually.

[15] W. F. Albright, "The Archaeological Results of an Expedition to Moab and the Dead Sea," *Bull. Amer. Sch. Oriental Res.*, No. 14 (April, 1924), pp. 2–12.

[16] Max Blanckenhorn, *op. cit.*, p. 111.

In an earlier decade, Walcott[17] had referred to the persistency with which the notion continued throughout nineteen centuries that the Dead Sea covers a district which before its submersion "was not only the Valley of Siddim but also the Plain of the Jordan." Walcott considered that the conversion of the Vale of Siddim to an embayment of the Dead Sea is an historic fact.

Proof of the rising lake waters during the historic period is found in the disappearance of the island of Rujm el-Bahr,[18] which was formerly exposed near the head of the lake and not far from the mouth of the Jordan. This land, visited by occasional picnic parties in the past and clearly visible on a photograph made in 1886, seen by the present writer, was possibly half an acre in size and its nature is unquestionable after inspection of the picture. The memory of an Arab photographer was vivid enough after 48 years to enable him to express an opinion as to the character of the exposed material.

Equally well substantiated accounts mention a Roman causeway which formerly crossed two miles of shallow sea from near Masada on the west coast to Point Molyneaux on El Lisan. Some archaeologist is said to have found traces of such a structure. Robinson[19] tells us of an Arab companion who reported that the "narrowest part or strait, between the peninsula and the western shoal or tongue of land" was once fordable, but the water was too deep at the time of Robinson's visit. He mentions a ford delineated "on Seetzen's map" and also adds that Irby and Mangles, coming from Kerak across El Lisan, "saw the ford 'indicated by boughs of trees' " and observed a caravan which had just landed on the opposite side. A Jerusalem civil engineer told the present writer that, in a conversation held with Arabs about 30 years ago, they mentioned having forded camels across this place in their boyhood when the water was less than a meter deep. Testimony as to the possibility of the existence of such a strait seems too numerous to be questioned. Moreover, plausibility of the reported fordings is manifested by Lynch's soundings of only 2–6 meters (6–18 feet) of water along this line. Karsten passed with his caravan in 1890, but Blanckenhorn and Palmer in 1894 found the road impassable for animals. The disappearance of the passage may have been due in part to earthquake action and[20] not entirely to rise of the water.

[17] Samuel Walcott, "The Site of Sodom," *Bibliotheca Sacra*, Vol. 25 (1868), pp. 112–51 (p. 118).

[18] Max Blanckenhorn, *op. cit.*

[19] Edward Robinson, Eli Smith *et al.*, *Biblical Researches in Palestine and the Adjacent Regions; A Journal of Travels in the Years 1838 and 1852*, 2nd ed., London, Vol. 2 (1856), pp. 521–22.

[20] Alois Musil, "Moab," *Arabia Petraea*, Vienna, Vol. 1 (1907), note on p. 172.

STRATIGRAPHY OF DEAD SEA AREA

Table I is a summary of formations, mainly compiled from reports by the Government geologist,[21] but with the aid of other publications supplemented by observations of the present writer. Since no accurate measurements of the geologic column have ever been made and since no late governmental results are published, it is necessary to consider estimates quite provisional, given merely to furnish a perspective for the discussions that follow and sure to be greatly modified when detailed work is conducted.

Rocks of various Paleozoic ages are known in Egypt and Sinai. Cambrian strata are exposed in only a few places in this region, but rocks of probably this age, a few feet in thickness, have been found along a fault line at the extreme base of the Transjordanian section, mainly south of El Lisan and in one or more localities as far north as Wadi Zerqa Ma'in.

Rocks classified as "Nubian sandstone" are apparently identical with vast sandstone areas of Jurassic and Lower Cretaceous age in Upper Egypt and Sinai. In Dead Sea latitudes these rocks are limited to the Transjordan side, where they form the lower part of cliffs bounding the lake for its entire length, extending far up Wadi Zerqa Ma'in and other lateral valleys.

Cenomanian rocks are also prominent, hundreds of feet thick, in walls of both sides of the lake throughout its length and for many miles up valleys on the east, overlying the "Nubian sandstone" and underlying Senonian rocks of the plateau surface. The usual fossil forms are found in certain zones common in the Cenomanian. According to Blake, "there seems to be no doubt that the top beds of the chalk series are Senonian and the lower beds are Upper Cenomanian," but the question of presence or absence of Turonian between them is in some localities unanswered. Many thin but conspicuous flint beds in both Palestine and Transjordan are probably mainly Senonian.

Rocks of Cretaceous age have not been subdivided with certainty in most of the highlands. It is known, however, that they form the greater part of the Transjordan surface for many miles east of Kerak and large plateau areas in the west between the lake and crest of the Jerusalem anticline. They may constitute the most widespread surface formations of the region.

Although Eocene is not positively known on highlands close to the Dead Sea, limestones of this age exist in an area south of Beersheba—many miles west of the lake—and again in Jordan Valley areas midway between Jericho and Beisan (Beth Shan). The exposures in the

[21] G. S. Blake, *op. cit.*

TABLE I

GENERALIZED STRATIGRAPHIC SECTION OF DEAD SEA AREA

Period	*Epoch or Stage*	*Estimated Thickness in Feet*	*Description*	*Localities*
QUATERNARY	Recent	50	Alluvium and fanglomerate	Jordan Valley and southern Ghor
	Pleistocene	200	Lake deposits	Jordan Valley and southern Ghor
TERTIARY	Pliocene	1,000	Basaltic flows	East side of Dead Sea (local)
			Limestones, clays, shales, marls and conglomerates	Top of Jebel Usdum
	Miocene	?	Salt, gypsum, etc.	Base of Jebel Usdum
	Eocene	2,000	Limestone, marl, etc.	Hills in Jordan Valley (local)
			Unconformity	
CRETACEOUS	Senonian	1,700	Gypseous limestone, poorly phosphatic beds, chalk and flint beds	Broad plateau surfaces in Transjordan and on eastern flank of Jerusalem anticline
	Turonian	0–100	Basaltic flows and ash beds	Few places in east wall of Dead Sea and in Transjordan
	Cenomanian	1,000	Hard limestones, dolomites, etc.	East and west walls of Dead Sea
	Lower Cretaceous	100	Oölitic sandy limestone	Valleys NE. of Dead Sea
JURASSIC		1,000	"Nubian" sandstone	East wall of Dead Sea
		?	Limestone	Valley NE. of Dead Sea and domes SW. of Dead Sea
			Unconformity	
CAMBRIAN		?	Limestone	Base of bluffs on east side of Dead Sea (few places only)

last-mentioned area are considerably folded and faulted. The lower part of Jebel Usdum may be of Miocene age, but no positively determined Miocene beds are known there or on highlands near the Dead Sea.

Although local deposits of Pliocene limestones, sands and clays are known in a few places on the uplands, the principal sediments of this age are in the depression itself at the south end of the Dead Sea. Arenaceous beds are said to be exposed in the upper part of Jebel Usdum, overlain by shales and gypseous beds containing some limestone bands. These beds constitute the Usdum series—possibly 1,000 feet of sands and shales, with gypseous marls and gypsum in the upper part—dipping steeply away from the salt plug on its margins. The exact age is uncertain; but, by comparison with Jordan Valley deposits, they seem to be Pliocene and perhaps partly Upper Miocene. The lowest known beds are shales containing plant remains and, according to Lees,[22] some fresh water fish, of which the possible age ranges from Eocene upwards. On the opposite side of the Dead Sea the Usdum sediments outcrop at Ed-dra, east of El Lisan, resting unconformably on the Cretaceous, but neither salt nor gypsum is present.

There seems to be no direct evidence of the age of Jebel Usdum salt which is intrusive in the Usdum series. It may be Miocene, like that in Egyptian structures having *diapir* relationship, or it may date from far back in geologic history like salt domes in southern Iran.[23] Since the lowest exposed beds are of fresh or brackish water origin, the salt may be foreign to the series.

The latest deposits in the Jordan Valley and in the Ghor south of the Dead Sea are alluvial sands, clays and fanglomerate beds near the mouths of dry valleys that enter the lake at various points. Some of these fans, near the lake, consist of terraces standing at various heights and indicating abandoned levels. Some of the slopes show considerable tilting in recent times, as for instance between Jericho and the Dead Sea in which area a difference of level of 100 feet or more is notable within a distance of 3 miles. A theoretical discussion of the origin of Palestine Quaternary deposits of Palestine was given by Blanckenhorn.[24]

In addition to predominantly sedimentary rocks of the Dead Sea area, there exist a few volcanic areas, much more widespread farther

[22] G. M. Lees, "Salt—Some Depositional and Deformational Problems," *Jour. Inst. Petrol. Tech.*, Vol. 17, No. 91 (1931), pp. 259–80.

[23] J. V. Harrison, "Salt Domes in Persia," *Jour. Inst. Petrol. Tech.*, Vol. 17, No. 91 (1931), pp. 300–20 (pp. 314–15).

[24] Max Blanckenhorn, *Origin and Formation of the Dead Sea*, Leipzig (1896); *Naturwissenschaftliche Studien*, etc., pp. 111–15.

north, in the vicinity of Lake Tiberias. In the Dead Sea latitudes of western Transjordan a number of necks and interstratified basalt flows and ash beds are known. They appear to have originated, in part, near the close of Cenomanian time, possibly to some extent in Turonian and again in late Pliocene time.

Scarcity of volcanic and ancient igneous rocks in the restricted Dead Sea area is not characteristic of the Palestinian group of countries as a whole, for igneous deposits are widespread in the Sinai Peninsula. Again, ancient igneous rocks cover broad areas between the Dead Sea and the Gulf of Akaba. According to Gleuck,[25] King Solomon's copper mines are found "about thirty miles south of the Dead Sea, on the eastern side of the Arabah"; but other copper mining centers were situated a few miles south and east in localities, occupied by settlements between 2,200 and 1,800 B.C., but abandoned about the last-named date and not resettled until about the 13th century B.C.

TECTONICS AND GEOLOGIC HISTORY

The precise geologic term to be employed for the Dead Sea graben has been debated. The designation "rift" was used by Gregory[26] for the Dead Sea and for similar grabens bounded by East African faults. Willis,[27] however, postulating certain genetics of the Palestinian depression, practically reversed the views of Gregory and proposed the term "ramp."

All visitors to the Jordan-Dead Sea Valley seem to have recognized the existence of an unstable state of equilibrium there. The depression was formed by a series of movements which apparently took place during the Miocene and Pliocene epochs with some extension into the Quaternary. There seems to be no support for Montague's view[28] that the "lake" had no existence prior to destruction of Sodom and Gomorrah and that, up to that date, the Jordan continued its southerly course as far as the Gulf of Akaba. Hull[29] explained that the strata east of the valley are relatively elevated (or those on the west side relatively lowered) by faulting, the existence of which had been recognized by Hitchcock,[30] Tristram,[31] Wilson[32] and Lartet.[33] Hume[34] de-

[25] Nelson Gleuck, "King Solomon's Copper Mines," *Illus. London News* (July 7, 1934), pp. 26 and 36.

[26] J. W. Gregory, *The Rift Valley and Geology of East Africa*, London (1921), 479 pp.

[27] Bailey Willis, *op. cit.*

[28] Edward P. Montague, *Narrative of the Late Expedition to the Dead Sea*, Philadelphia (1849), p. 190.

[29] Edward Hull, *Mount Seir, Sinai and Western Palestine*, London (1885), p. 129.

[30] Edward Hitchcock, "Notes on the Geology of Several Parts of Western Asia; Founded Chiefly on Specimens and Descriptions from American Missionaries," *Trans. Assoc. Amer. Geol.* (1840–42), pp. 348–421 (p. 368).

scribed the Gulf of Akaba (southern extension of the Arabah) as a "rift" valley.

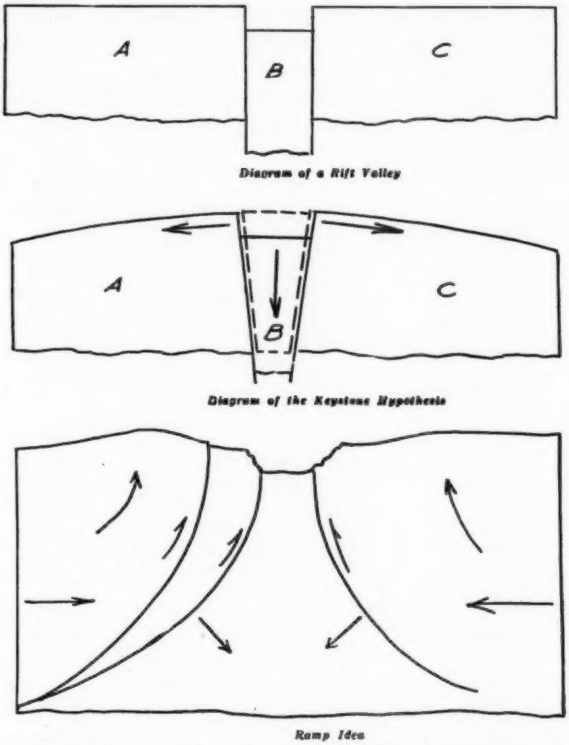

FIG. 3.—Progressive conceptions of nature of Dead Sea faulting (after Willis).

That Dead Sea tectonics were not at all understood until recent years is evinced by descriptions of Leopold von Buch (quoted by Robinson)[35] and Coleman.[36] The last-mentioned writer called the

[31] H. B. Tristram, *The Land of Moab*, New York (1873), 2nd ed., p. 329.

[32] Article entitled "Arabeh" in Smith's *Dictionary of the Bible*.

[33] Louis Lartet, author of de Luynes' Volume III, *op. cit.*

[34] W. F. Hume, "Rift Valleys of Eastern Sinai," *Geol. Mag.*, N.S., Decade IV, Vol. 8 (1901), pp. 198–200.

[35] Edward Robinson, *Biblical Researches in Palestine, Mount Sinai, and Arabia Petraea, A Journal of Travels in the Year 1838*, Vol. 2 (1841) 435 pp.

[36] Lyman Coleman, "The Great Crevasse of the Jordan and of the Red Sea," *Bibliotheca Sacra* (Andover), Vol. 24 (1867), pp. 248–62.

graben "a fissure, a crevasse" formed by some "stupendous convulsion." Coincidences as to structural similarity between this feature and the rift valleys of East Africa are remarked by Gregory.[37] The East African rift valleys were supposed to constitute a structural extension of the Dead Sea-Gulf of Akaba graben. Northward from the Jordan Valley the *graben* breaks up by *virgation*.[38]

Bonney[39] may have been the first to object to calling the Dead Sea a "rift valley." He quotes Suess[40] to the effect that the Jordan Valley should accurately be termed a "sinking graben" and based his objection on the idea that "rift" is not an accurate translation for "graben." Bonney suggested "trough valley" as a substitute applicable to the Jordan-Dead Sea feature.

Some early writers supposed that the Dead Sea valley was once an arm of the Gulf of Akaba. Tristram[41] noted that the forms of life in the Dead Sea Valley were quite unlike species in the surrounding region but bear a strong affinity to those in the Ethiopian region with a trace of Indian admixture. Bonney's discussion evinces a belief that the Jordan was once a tributary of the Gulf of Akaba.

The Dead Sea is approximately twice as salty as the Mediterranean. Although the Caspian is noted for its fish, the Dead Sea contains practically no life, except off Wadi Mojib, where live fresh water fish are sometimes carried by streams as far as a point where water density becomes 1.115 as opposed to the specific gravity of the lake itself which is in places as high as 1.250. The only other life forms are small *foraminifera* found in the bottom mud but Ehrenberg proves that not one of these belongs to any species discovered in the Red Sea. Reclus supposed that the high magnesium chlorides and bromides render the water "completely destructive to animal life." Since the waters contain no iodine it seemed probable to Reclus that the Dead Sea never constituted part of the ocean, although the contrary hypothesis had been previously expressed.

The fault planes enclosing the graben are not simple ones; neither are they perfectly vertical; they are not normal faults, but indicate thrusting. It was partly the conception of the direction of the fault dips which led Willis to differ from Gregory as to the nature of the

[37] J. W. Gregory, *op. cit.*

[38] Karl Diener, "Die Struktur das Jordanquellgebietes," *Akad. Wiss. Wien. Math. Naturw.*, Vol. 92 (1885), pp. 633–42.

[39] T. G. Bonney, "The Kishon and Jordan Valleys," *Geol. Mag.*, N.S., Decade V, Vol. 1 (December, 1904), pp. 575–82 (p. 577).

[40] Eduard Suess, *Antlitz der Erde*, Vol. 1, pp. 481 *et seq.*

[41] *The Fauna and Flora of Palestine* (1884), p. 16.

tectonic processes. Willis' view of the genesis of the graben requires that the faults represent thrust planes inclined downwards away from it, whereas Gregory believed them to be normal faults. The present writer found much as to dips and distribution of bounding faults tending to confirm the views of Willis.

FIG. 4.—Looking east up Wadi Zerqa Ma'in, Transjordan; showing east dips, basalt capping (on left), "Nubian sandstone" and Cenomanian sediments. One *en échelon* fault crosses valley near limit of view.

Displacements underlie the valley as well as the highlands. Major faults do not extend throughout the entire length of the "ramp" as continuous bounding planes, but they coincide with one or the other mountain wall for a few miles, then curve off into the lake or the highlands, as the case may be, giving an *en échelon* effect. Yet physical consistency throughout the *graben* must be presumably explained by some fundamental cause. Faults exist aside from those affecting the *graben* itself, as can be seen (a) in the valley of Marmuk River between El-Hammeh and Lake Tiberias, (b) along the Amman highway

FIG. 5.—View of one *en échelon* fault where it strikes Marmuk River, 73 miles north of Dead Sea, showing Upper Cretaceous on left and Miocene overlying basalt flow onright.

FIG. 6.—Looking north along fault line from point midway between Es Salt and Suweila, Transjordan.

near Es Salt, (c) throughout several miles northeast of Nablus, and (d) in crossing Zerqa Ma'in about 5 kilometers (3 miles) above its mouth. Blanckenhorn and Blake, in delineating Palestinian geology, mapped the trend of closely associated faults which intercept Cretaceous hills on both sides of the Dead Sea and the writer has observed faults of this description that are unreported in the literature.

FIG. 7.—Intraformational folding in Cenomanian limestones, Amman, Transjordan.

Anticlines and domes likewise exist, the structural geology of Palestine and western Transjordan being largely an alternation of gentle folds, the axes of which trend diagonally across the great valley from Palestine into Transjordan. In fact, a perfect grid of structures can be mapped—including one system which was formed possibly in early Tertiary time, but was later cut by development of the north-south "ramp" and by accompanying phenomena. Some of the folds grade into faults and some of the last-named are flanked by anticlines.

DESCRIPTION OF JEBEL USDUM

Although the land surface of the Jordan Valley and Southern Ghor is composed mainly of Tertiary and Quaternary sediments, there are a few places, as between Jericho and Beisan, where domes (or hemi-

domes) of Cretaceous or Eocene limestones, and some faults, are observable far out in the valley. From a structural standpoint, the most interesting Dead Sea feature is Jebel Usdum—sometimes known as "Khasm Usdum," "Mount of Sodom," etc.—a hill 8 kilometers (5 miles) long and 4.5 kilometers (3 miles) wide, composed in part of

FIG. 8.—Rock salt on coast of Jebel Usdum. (Photo used through courtesy of American Colony Stores, Jerusalem. Copyrighted by American Colony Stores.)

rock salt, which rises 234 meters (742 feet) above water level, but nevertheless stands 159 meters (550 feet) short of the Mediterranean surface.

Jebel Usdum was perhaps first described geologically by Hitchcock,[42] although more than forty years later Hull[43] wrote that "for the

[42] Edward Hitchcock, *op. cit.*

[43] Edward Hull, *op. cit.*

first time the upper surface of this remarkable saliferous plateau was examined by an European." A free-hand sketch of the coast of Jebel Usdum was given by Lartet.[44] The mountain is not composed entirely of salt, as might be inferred from reading certain non-geological accounts, although the lower part is a pure compact crystalline salt mass reported as containing 98–99.5 per cent of sodium chloride,[45] the remainder being sulphates of calcium and sodium ("white to gray and

FIG. 9.—Coast of Jebel Usdum. (Photo used by courtesy of David A. Sutherland.)

black, with pegmatic-like veins") over 30 meters (more than 90 feet) thick in some parts. The salt is deeply eroded, caverned and crevised. Above the salt is a variegated succession of red, green and gray gypsiferous marls. Walking on the hill is difficult, for yawning fissures with glistening steep walls are numerous. Lartet, Hull, and Blanckenhorn crossed Jebel Usdum on foot, but Lartet supposed the age to be Senonian,[46] perhaps because fragments of Cretaceous rock are strewn

[44] L. Lartet, *op. cit.*, Plate 3.

[45] H. J. Anderson, "Geological Reconnaissance of Part of Holy Land," in W. F. Lynch's *Official Report of the United States Expedition to Explore the Dead Sea and the River Jordan*, Baltimore (1852).

[46] Max Blanckenhorn, *op. cit.*, pp. 111–13.

upon it.[47] Blanckenhorn was under the impression that the age of the salt was Quaternary, but its origin puzzled him nevertheless.

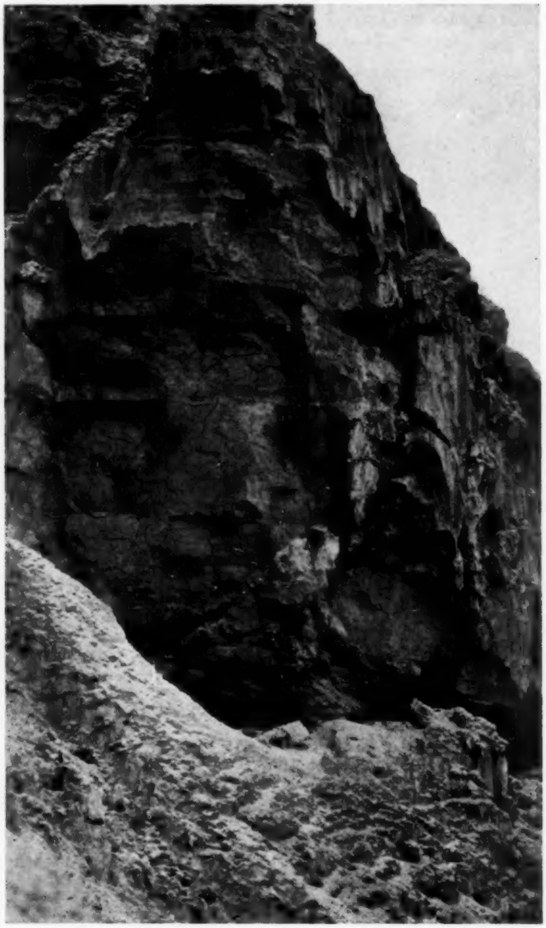

FIG. 10.—Rock salt on Jebel Usdum, Palestine.

The intrusive nature of the Jebel Usdum salt was apparently first recognized by Wyllie, Campbell, and Lees,[48] although Blanckenhorn[49]

[47] Noted by Ludwig Salvator, in "Jebel Usdum," *Mitt. d. k. geog. Ges. Wien* (1873).

asserted the hill to be an uplifted *horst*. It has previously been generally considered an old deposit of the Dead Sea itself. In the words of Lees,[50]

Only in two places throughout the length of the valley have these diluvial beds suffered any dislocation—namely, at Qarn-al-Ahmar and at Jebel Usdum. In both cases the disturbance is due to intrusive bodies which have formed elongated domal structures in the Pliocene to Miocene deposits, underlying the diluvial beds. The latter have also been affected by the movement, although to a lesser degree. At Jebel Usdum, the diluvium has been elevated to a height of several hundred feet above its normal level in the surrounding country. The intrusive body at Qarn-al-Ahmar is basalt and at Jebel Usdum it is salt.

It is apparent that salt movement may still be taking place, and Lees adds that—

It is interesting to speculate whether the story of Sodom and Gomorrah may not have been in some way connected with the movement of the salt dome.

David A. Sutherland, in a personal letter to the writer, dated November 28, 1933, describes a "salt cave which has a vertical chimney" to the air about 150 feet above, where the air was "positively chilly" at night and his party "had to shelter with big rocks at our backs and to shiver with cold," although outside the day-time "temperature was 115 degrees in the shade." Wyllie[51] also noticed a tunnel-like cave in the hill.

The best known feature, in legend and history, of Jebel Usdum, is, however, the "pillar of salt." Lynch[52] wrote that, when sailing southward parallel with this mountain—

to our astonishment, we saw on the eastern side of Usdum, one third of the distance from its north extreme, a lofty, round pillar, standing apparently detached from the general mass. . . . We found the pillar to be of solid salt, capped with carbonate of lime, cylindrical in front and phramidal behind. The upper or rounded part is about forty feet high, resting on a kind of oval pedestal, from forty to sixty feet above the level of the sea. It slightly decreases in size upwards, crumbles at the top, and is one entire mass of crystallization. . . . Its peculiar shape is doubtless attributable to the action of the winter rains.

It is not strange that the superstitious Israelites evolved a legend

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[48] B. K. N. Wyllie, "The Geology of Jebel Usdum, Dead Sea," *Geol. Mag.*, Vol. 68, No. 606 (1931), pp. 360–72.

[49] Max Blanckenhorn, *Naturwissenschaftliche*, etc., pp. 111–13.

[50] G. M. Lees, *op. cit.*, pp. 265–8.

[51] B. K. N. Wyllie, *op. cit.*, p. 369.

[52] W. F. Lynch, *op. cit.*, p. 307.

according to which Lot's wife was miraculously transformed into a pillar of salt, for at least one salt pillar existed until within a few years ago on the seaward coast of Jebel Usdum even if it does not still stand there. It was mentioned by the historian Josephus Clement about 2,000 years ago and reported by Iraneous 200 years later. Nearly a century ago Montague was superstitiously impressed[53] on seeing "an immense column rounded and turret-shaped" which he was credulously led to believe was "the pillar of salt in which Lot's wife was encased."

Aside from the fact that credentials are superfluous as to the identity of objects of legendary origin, it seems improbable, judging by the reported column's geologic position and form, that only a single pillar of the sort stood for approximately 4,000 years on a precipitous hillside in an earthquake region. It is more likely that sometimes one mass, sometimes another on the same hill, may have been called "Lot's wife" during intervening millenniums.[54]

OIL AND ASPHALTIC SEEPAGES

Known types of possible oil indications in the Dead Sea area are (a) oil-saturated sands and other seepages of liquid petroleum, (b) effusions of bitumen from the lake, and (c) outcrops of bituminous rocks. Of these the second and third types are most common.

(a) *Oil-saturated sands and other seepages of liquid petroleum.*—The most prominent Palestine seepage is situated in Wadi Mahawuat,[55] 13 kilometers (8 miles) north of the southwest corner of the Dead Sea and possibly 3 kilometers (2 miles) west of the north end of Jebel Usdum. This locality was described by Blake[56] and earlier by Blanckenhorn[57] who gives a sketch map of the valley and its deposits. Pleistocene and Recent sands and gravels, found along many rods of valley wall (reported by Blanckenhorn as being 4,000 cubic yards in net volume but considered by Blake as "much underestimated") are saturated with a black, oily and somewhat spongy mass of tar,

[53] Edward P. Montague, *op. cit.*, pp. 200–2.

[54] Wyllie tells us, in reference to the pillar called "Lot's wife" (*op. cit.*, footnote on p. 369): "A stronger tradition seems to attach Lot's name to pinnacles of calc-sinter which have been formed along the eastern rift-fault, on the Transjordan side some distance south of Wadi Mojib. These are called Mart Lut, Bint Lut, and Kelb Lut (Lot's Wife, Daughter and Dog).

[55] In this report the spelling of geographic names, except those directly quoted, is from a map published in 1931 by the Geographical Section of the General Staff of the British War Office.

[56] G. S. Blake, *Mineral Resources of Palestine and Transjordan*, Bull. 2, Jerusalem (1930), pages 13–25 being devoted to petroleum, bitumen, and bituminous limestone.

[57] Max Blanckenhorn, *op. cit.*, p. 117.

evidently a partial desiccation of petroleum which emerges from a fault plane between Tertiary sediments of the Dead Sea graben and Upper Cretaceous strata in the uplands. Lartet[58] gives a pictorial sketch of Wadi Mahawuat. This seepage, in the words of Wade,[59] lies—

> within a few miles of Jebel Usdum, the Mount of Sodom, and, so far as one can ascertain, Sodom was situated on one of the fissures from which the flood of petroleum . . . may have originated. May we not imagine, then, some earthquake setting fire to either this or a similar flood of bitumen, or even an outburst of natural gas, which, taking fire, caused the destruction of this famous though ill-reputed city?

The second most important seepage, also mentioned by Blanckenhorn, is in Wadi Sebbeh, close to the site of the former settlement of Masada—the last stronghold of the Jews against the Romans—where oil exudes from dolomitic Turonian or Upper Cenomanian beds about 3 kilometers (2 miles) west of the Dead Sea and 30 kilometers (20 miles) north of its south end. The *Geography of Strabo*[60] mentions this seepage where,

> near Moasada are to be seen rugged rocks that have been scorched, as also, in many places, fissures and ashy soil, and drops of pitch dripping from smooth cliffs.

Blake mentions additional "oil seepages" in Transjordanian waters at (1) Ain Ammu Dhheib "and Bind Sheikh Lut," south of the mouth of Wadi-el-Mojib and at (2) Ed-Dra east of Lisan Peninsula. The present writer has found no person who has actually seen these last-described phenomena, although they were mentioned by Wade and others and referred to as "seepages of light oil."

(b) *Bitumen exudations from the lake.*—Aside from actually known seepages there are widespread occurrences of pure black bitumen, sometimes weighing as much as 100 pounds, which ascend in masses from the south half of the Dead Sea "as if squeezed out of a fissure," notably between Wadi-el-Mojib and Ain Jidi (Engedi) 30 to 40 kilometers (20 to 25 miles) from the north end of the lake. The ancient name—"Lake Asphaltites"—is doubtless due to the presence of this bitumen. The nomadic Nabataeans who dwelt at Petra to the southeast are known to have had an extensive trade in myrrh and spices from Arabia Felix, which they sent to the seaports, and in Dead Sea bitumen which they sent to Egypt. Blake states that blocks of several tons rose in the past and that an aggregate weight of 150 tons was collected after an effusion at Ain Jidi in 1925. Small samples of this

[58] L. Lartet, *op. cit.*, Plate III.

[59] Arthur Wade, *op. cit.*

[60] *The Geography of Strabo*, Book XVI, Chapter 2, Art. 44.

material, picked up on the shore, are in the possession of friends of the writer. The substance has a jet black color, a strong smell of crude petroleum and a bright conchoidal fracture. The following analysis was made by the Imperial Institute.[61]

Moisture	0.49
Hydrocarbons	99.04
Ash	0.47
Total	100.00
Specific gravity	1.115*
Fusion point	121°C.

* Another report makes it 1.104.

One of the earliest geological descriptions of this material was in a statement by Hitchcock, who, referring to Dead Sea bitumen deposits,[62] tells us that, after the earthquake of 1834, a large quantity of the substance drifted ashore near the south end of the sea and that Arabs brought six thousand pounds to market. And again, he says that, after the earthquake of 1837, a mass "like an island or a house" rose to the surface and three thousand dollars worth was sold by the inhabitants. Nineteen centuries earlier the Jewish historian Josephus had written that black masses of asphaltum rose through the sea and "floated on the surface, having the form and size of headless oxen." Wade thinks the bitumen deposits of the Dead Sea itself must have been more widespread in the past than at present, "judging by the widespread fame of Dead Sea bitumen among the ancients and extensive uses made of it as an article of commerce."

(c) *Bituminous rocks.*—On the north and east sides of Jebel Usdum, geologists working under J. McClelland Henderson in the employ of David A. Sutherland, reported petroliferous odors in shale beds of unknown age involved with the salt uplift. Bituminous impregnations in Upper Senonian limestones are reported at many points west of the Dead Sea and in "Nubian sandstone" east of El-Lisan and south of Wadi-el-Mojib.

At Nabi-Musa (mistakenly considered by the Arabs the tomb of Moses) and at Jebel Kahmun, 18 kilometers (11 miles) east of Jerusalem and 6 kilometers (4 miles) west of the northwest corner of the Dead Sea, is an area of about 8 square kilometers (3 square miles) of Upper Senonian rocks, having a reported thickness of 10 meters (30 feet), which contains[63] about one per cent of free petroleum and 20 to 23 per cent of bituminous matter. This area of bituminous rock

[61] G. S. Blake, *op. cit.*, p. 16.

[62] Edward Hitchcock, *op. cit.*, p. 371.

[63] G. S. Blake, *op. cit.*, p. 14.

is probably the most extensive and is used at Bethlehem for fabricating souvenirs. The following are two analyses of this rock, which is locally called Hajar Musa (Moses' stone). Arabs have told the present writer that, during the pilgrimage of Easter week, when hundreds of Mohammedan pilgrims walk to Nebi Musa, they "are not obliged to carry fuel, for the rocks will burn."

FIG. 11.—Lump of bitumen floating in Dead Sea. (Photo used through courtesy of George S. Blake, geological adviser of Palestine Government.)

ANALYSES OF BITUMINOUS LIMESTONE FROM NEBI MUSA

	*No. 1**	*No. 2*†
$CaCO_3$	68.73	82.10
$MgCO_3$	0.27	0.00
Silica	——	1.95
Al_2O_3 and K_2O_3	——	1.95
Organic matter	——	13.55
Bitumen	25.00	——
Residual	6.00	——
Total	100.00	99.55

* Edward Hitchcock, *op. cit.*, p. 364.
† H. J. Anderson, in Lynch's "Official Report," etc., p. 155.

SEEPAGES DURING HUMAN HISTORY

The historical aspect of the Dead Sea bitumens may be of interest, for the fourteenth chapter of Genesis (10th verse) tells us that "the

vale of Siddim was full of slime pits" in which five Elamitish kings were trapped. Tales of "slime pits" are not limited to the Bible, for less than a century ago Lynch[64] described Wadi Zuweirah, at the north end of Jebel Usdum as "a broad, flat, marshy delta, the soil coated with salt and bitumen, and yielding to the foot." Some distance north of the pillar of salt a sailor "made his way with difficulty for more than a hundred yards over black mud, coated with salt and bitumen," and the description easily parallels the Genesis account. Lynch tells us that sand on the shore of El Lisan was likewise encrusted with salt and bitumen. He evidently believed[65] the sites of Sodom and Gomorrah to lie submerged beneath the lake, for he asserts that the southern embayment

> most probably covers the guilty cities . . . and that many fathoms beneath it lay embedded the ruins of the ill-fated cities of Sodom and Gomorrah.

Many writers contend that the "slime pits" recorded in Genesis were bitumen pits and that the Dead Sea has since risen and submerged them together with the ancient cities of Sodom and Gomorrah. We are informed that in the year 311 B.C. Antigonus sent Hieronymous of Cardia with an army to capture the Dead Sea asphalt works from the ruler Nabatei.[66] These seepages were again referred to about 80 B.C. by the historian Diodoras Siculus[67] and about 30 B.C. by Strabo. The appearance of the bitumen is said always to be preceded by earthquakes. The last-named historian[68] wrote that the material

> is blown to the surface at irregular intervals from the midst of the deep, and with it rise bubbles, as though the water were boiling; and the surface of the lake, being convex, presents the appearance of a hill. With the asphalt there arises also much soot, which, though smoky, is imperceptible to the eye; and it tarnishes copper and silver and anything that glistens, even gold, and when their vessels are becoming tarnished the people who live around the lake know that the asphalt is beginning to rise; and they prepare to collect it by means of rafts made of reed. The asphalt is a clod of earth, which at first is liquefied by heat, and is blown up to the surface and spreads out; and then again, by reason of the cold water, the kind of water the lake in question has, it changes to a firm, solidified substance, and therefore requires cutting and chopping; and then it floats, because by the nature of the water, owing to which, as I was saying, there is no use for divers; and no person who walks into it can

[64] W. F. Lynch, *op. cit.*, p. 306.

[65] W. F. Lynch, *op. cit.*, pp. 307 and 310.

[66] E. Rich, *Atlas Antiquus*, text facing Map 18.

[67] *Bibliotheca*, Book XVI, Chap. 20, Books I–II, Capt. XXIX; also *Hist. Universe*, Books VI–XIX, Chap. XXV.

[68] *Geography of Strabo*, Book XVI, Chapter 2, Art. 42.

immerse himself either, but is raised afloat. They leash the asphalt on rafts and chop it and carry off as much as they each can.

Discussing these accumulations, Ritter[69] postulates that there are far greater accumulations at the bottom of the sea than along the rocks on the shores and that the deposits are detached from the bottom and brought to the surface by violent earthquakes. Walcott[70] likewise assumed that the slime pits of the Vale of Siddim were "wells of asphaltum or bitumen, probably of various dimensions, sufficient, . . . either from their number, or size, or both, materially to affect the issue of the battle. Eighteen centuries earlier Josephus,[71] referring to the invasion of Chedorlaomer and his allies, had written that

they pitched their camp at the vale called the Slimepits, for at that time there were pits in that place, but now, upon the destruction of the city of Sodom, that vale became the *Lake Asphaltites*, as it is called.

The bituminous nature of the southern area is, therefore, a well substantiated tradition of the Jewish nation, and the story of Sodom and Gomorrah may be considered a well authenticated epic.

GEOLOGIC EVIDENCES RELATIVE TO SODOM AND GOMORRAH

Although the seepages are important historically, the argument from hydrology may be necessary to indicate that ancient Sodom and Gomorrah stood in an area which is now water. The strongest proof that these settlements were at the south end of the Dead Sea is, however, offered by geology. The inspired author who fancied that Lot's wife, fleeing from blazing Sodom, was transformed into a "pillar of salt" was doubtless influenced by knowledge of the existence of an actual physical feature of that sort on the hill in question.

Forces corresponding to the Genesis description may have afflicted the ill-fated cities, either through volcanic agencies or by the combustion of local materials. Various writers have conjured fanciful hypotheses to explain the association of bituminous substances with destruction of these cities and one writer[72] explained that

the cities stood on a soil broken and undermined with veins of bitumen and sulphur . . . . The walls . . . were perhaps built from the combustible materials of the soil.

[69] Carl Ritter, *Comparative Geography of Palestine* (translated by W. L. Gage, Edinburgh, 1866), pp. 171–3; 350–80.

[70] Samuel Walcott, *op. cit.*, pp. 120–21.

[71] Flavius Josephus, *Antiquities of the Jews*, Book I, Chapter 9.

[72] Milman, *History of the Jews*, 1, pp. 15, 16.

Much more recently a similar hypothesis was advocated by Wright[73] who, quoting Emerson,[74] pointed to a similarity between structural and stratigraphic conditions of the Dead Sea area and oil-field conditions. Blanckenhorn[75] supposed that the phenomenon was "showers of ashes"—a view not so improbable as it may sound, for tuff and basalt flows and accompanying roots of fossil vents (previously studied by Blanckenhorn)[76] are conspicuous near the mouth of Zerqa Ma'in in the east wall of the lake about 50 kilometers (slightly over 30 miles) north of the probable site of Sodom. Other volcanic plugs are distributed throughout western Transjordan in Dead Sea latitudes and interstratified tuff beds can be seen in various parts of the late Tertiary column. Burkhardt[77] quotes authentic accounts of eye-witnesses of eruptions near Medina in the Hedjaz as recently as the 13th century, but he inclines to the view that no volcanic activity has taken place there for several times that period, in which case an ash shower could not have been responsible for the fate of Biblical cities.

Although Wyllie[78] acknowledges a possible association between volcanology and the destruction of Sodom and Gomorrah, the present writer, after studying relationships of western Transjordanian igneous and pyroclastic beds to existing topography, is convinced that lava or ash eruptions did not occur close to the Dead Sea as recently as four millenniums ago.

On the other hand, bitumen, petroleum or natural gas may have emerged, even in historic times, whenever disastrous earthquakes took place during shifting of the bounding faults. Seepages catching fire from lightning or from human agencies might adequately account for the combustion recorded in Genesis. It is likewise probable that inflammable gas, in association with salt water, has emerged within walking distance of Jebel Usdum during the historic period, not in a single spot alone, but along known fault planes on perhaps both sides of the valley. The rôle or faults as channels for the escape of bituminous or other materials is evinced by sinter deposits on surface trends at several points along the Dead Sea walls.[79] Other phenomena men-

[73] G. F. Wright, *Scientific Confirmations of Old Testament History*, Oberlin, Ohio (2nd ed., 1907), p. 144.

[74] B. K. Emerson, *Proc. Amer. Assoc. Adv. Science*, Buffalo, N. Y. (1906), pp. 109, 111.

[75] Max Blanckenhorn, *op. cit.*, p. 119.

[76] Max Blanckenhorn, *op. cit.*, geologic cross section (Fig. 70, p. 209) and cross section of neighboring lava flows (Fig. 68, p. 207).

[77] Burkhardt, *Voyage en Arabie*, Vol. 2, p. 98.

[78] B. K. N. Wyllie, *op. cit.*

[79] Max Blanckenhorn, *op. cit.*, p. 225.

tioned in the Bible[80] may likewise be symbolized by natural gas seepages in a part of the world where the existence of this fluid is widespread and frequently escapes to the earth's surface.

POSSIBLE SOURCE AND RESERVOIR ROCKS AND COVER

Since Upper Cretaceous strata, 2,000–3,000 feet thick, underlie more than half of Palestine and of the visited portions of Transjordan, it is evident that vast areas exist in which petroleum "source rocks" may be present. Specifically, Upper Senonian limestones throughout wide areas in Palestine and northern Transjordan are bituminous, as already explained, and in some places they contain 10–16 per cent crude oil. Whether these constitute actual source beds has not been chemically or microscopically determined, but they are significant evidences that certain strata are petroliferous. Consequently liquid petroleum may have accumulated, if it is assumed that reservoir beds, cover and favorable structures exist.

Nothing is known of definite reservoir rocks in the Upper Cretaceous of Palestine and Transjordan. However, since the strata are almost if not entirely limestones, cavernous at the surface, some underlying bed may be competent to form a reservoir. Suitable containers of Lower Cretaceous and Jurassic age, with correspondingly thick covers, are known to exist.

As to cover, there is no doubt that a large number of individual beds—limestone, chert, etc.—are competent to prevent the entire escape of any existing oil. Large areas both in Palestine and Transjordan have adequate limestone thicknesses overlying the Senonian petroliferous "source beds."

Nevertheless, none of the plateau areas, even those having Upper Senonian surface beds, are considered probably oil-bearing. The petroliferous provinces most highly approved are those, inside the "ramp" valley, where the Senonian beds are overlain by hundreds or thousands of feet of fine-grained limestone, marls and clays of Tertiary age, unquestionably competent to act as cover.

In short, the down-faulted lowland areas and not the plateau may more logically have oil potentialities. "Ramp" areas of the Dead Sea

[80] For instance, Moses' "burning bush" in Sinai (Exodus, iii, 2) and the "fiery furnace" of Shadrach, Meshach, and Abednego in Assyria (Daniel, iii, 23–27). One can easily walk across blazing outcrops in Mesopotamia from which natural gas still escapes—impressive but giving off little heat. The pillars of fire historically reported as being worshipped by Babylonian followers of the god Ormuzd were possibly caused by natural gas escaping from oil deposits and ignited by the priests. Again, someone has hinted that, when the water of the pool of Bethesda in Jerusalem was "troubled" by an angel (John, v, 4), for the purpose of indicating the auspicious moment for impotent persons to descend for healing, the visualized phenomenon may actually have been escaping bubbles of gas (since Jerusalem is situated on an anticline).

and its graben extensions north and south are underlain by Pleistocene and Tertiary strata, which cover the Senonian source rocks, and some part of these depressed areas may conceivably contain favorable structure. Jebel Usdum appears to be a "perforated dome" of the Roumanian type. The salt dome was "detailed" geologically by J. A. Childs and R. H. Mitchell, acting for Sutherland under the direction of Henderson, but the results of their work are not at present available. In addition, it is possible that Lisan Peninsula, likewise situated in Transjordan and 5–8 kilometers (8 to 12 miles) northeast of Jebel Usdum, may owe its presence to a concealed salt intrusion aligned with Jebel Usdum.

The axial prolongation of Jebel Usdum southeast of the Dead Sea, however, encounters an area of Upper Senonian strata, where oil prospects may be less favorable (even if suitable doming be present) than at Jebel Usdum or El Lisan. Structural features (anticlines, homoclines and domes, exposing pre-Senonian strata) are found southwest of the Dead Sea in the direction of Beersheba.

POSSIBILITY OF METAMORPHISM AND PAST LEAKAGE

In all undrilled areas, if the geology be otherwise favorable, it is essential to raise the question whether oil, if it once existed, may have been removed or rendered non-commercial owing to metamorphic action. This may have taken place under domes on the Jerusalem and Es Salt anticlines, and such structure might now be favorable if oil indications existed in strata of Lower Cretaceous, Jurassic, Triassic or Paleozoic rocks, which is not the case. Fundamentally there is no known reason why these structures may not be productive, yet no surface evidences justify expectation of oil in pre-Senonian rocks. The lack of seepages in the earlier sediments may be either (1) absence of source beds or (2) too intensive metamorphism.

Structures of possible interest inside the "ramp" valley lie at a distance from lines of most intensive folding, such as the Jerusalem and Es Salt anticlines. Hence no special reason exists for supposing that metamorphism has been sufficient to destroy or drive away the oil from given structures. If the strata had been metamorphosed, any surface bitumen discovered would most probably be a desiccated variety rather than the pure and easily volatile deposits that rise from Dead Sea depths and appear in the pores of Wadi Mahawuat sands.

Another important question is whether, since greater exudations of crude oil and possibly gas appear to have taken place within historic time, the supplies may be practically exhausted. Only drilling can answer this question. Whether commercial supplies exist in the

Dead Sea area or not, the region is on record as having produced bitumens or petroleum since earliest known habitation and hence is of definite scientific and historic importance.

ACKNOWLEDGMENTS

During his first Palestine and Transjordan field trip, the writer had the valuable collaboration of David A. Sutherland—the one-time holder of large exploration permits under a former Mining Ordinance. The writer's journey to the Dead Sea in 1929 was made in company with this gentleman, H. Hope Henderson (mining engineer) and George S. Blake (Government geological adviser) to all of whom the writer is indebted for many courtesies. A later visit of the writer was made in 1934 for American interests. Cordial moral support on the last trip came from J. McClelland Henderson (mining engineer) of Jerusalem, and general advice was furnished by A. P. S. Clark, manager of Barclay's Bank (Dominion, Colonial and Overseas, Ltd.). Helpful consideration was given in Government offices by Fawcett Pudsey (director of the Department of Public Works), by George S. Blake and by Ali Beg Tubarra (director of Agriculture, Forests, and Mines of Amman, Transjordan). Thanks are tendered to all these individuals and departments for their helpfulness.

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GEOSYNCLINAL BOUNDARY FAULTS[1]

W. A. VER WIEBE[2]
Wichita, Kansas

ABSTRACT

In textbooks of geology a geosyncline is described and pictured as a more or less symmetrical trough with the greatest depth near the axis or middle. During the last 8 years the writer has made a special study of the distribution and thickness of Paleozoic and Mesozoic sediments in the United States. These studies indicate that the greatest depth in a geosyncline lies along one side and immediately adjacent to the land mass which supplied sediments to the geosyncline. This conclusion warrants two corollaries important from the standpoint of the structural or tectonic history of the region involved. First we must assume that stupendous boundary faults of gigantic throw are present. These act as shear planes or zones for a gigantic couple consisting of a spasmodically rising landmass on one side and a spasmodically sinking geosyncline on the other. The second conclusion is that parallel faults are present in the foundation of the geosyncline. Movements along these parallel faults caused the folds which are sometimes present in geosynclinal sediments. In other words the folds are not directly due to tangential thrust, but rather to vertical movement in buried fault blocks.

History.—The term *geosyncline* was introduced by J. D. Dana in 1873. He was not the first, however, to point out the characteristics of such geologic features. The credit for this must go to James Hall who described the Appalachian "syncline" as early as 1857 and elaborated upon his concepts in 1861 and again in 1883. He pointed out that mountains are apt to occur where sediments are thickest and that such sediments accumulate in a vast syncline adjacent to land which rises periodically. The land from which the sediments in the Appalachian syncline came was described by Hall in 1857, but was not named until 1897 when Williams applied the name of Appalachia to it.

The most complete and exhaustive description of geosynclines is contained in the presidential address delivered by Charles Schuchert in 1922 before the Geological Society of America. He classifies them according to their complexity and relative position into monogeosynclines, polygeosynclines, mesogeosynclines, and parageosynclines. His definition of monogeosynclines is that they are "long, comparatively narrow, deeply subsiding, but always shallow water, smaller primary geosynclines situated within a continent along the inner side of borderlands. An example is the Appalachian geosyncline."

Characteristics of Appalachian geosyncline.—The characteristics of the Appalachian geosyncline must be deduced from a study of the

[1] Read before the Association at the Tulsa meeting, March 20, 1936. Manuscript received, March 20, 1936.

[2] Professor of geology at the University of Wichita.

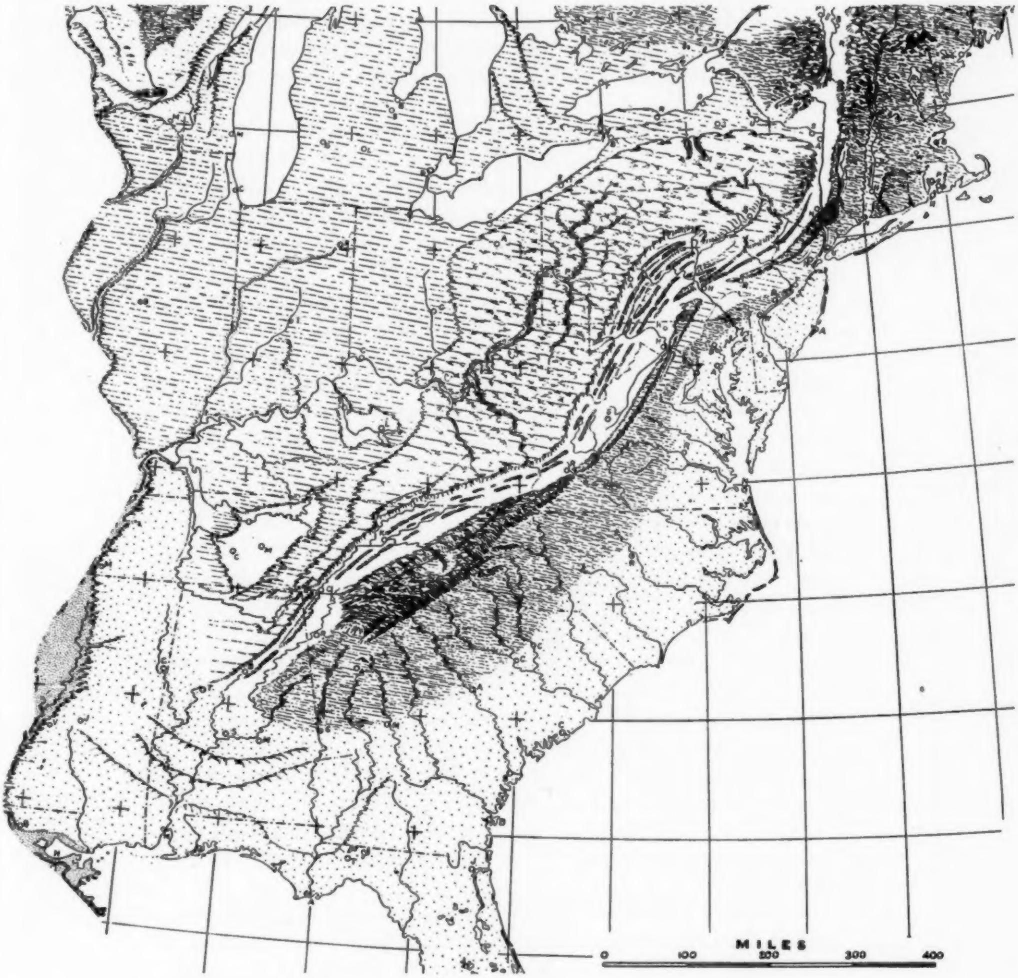


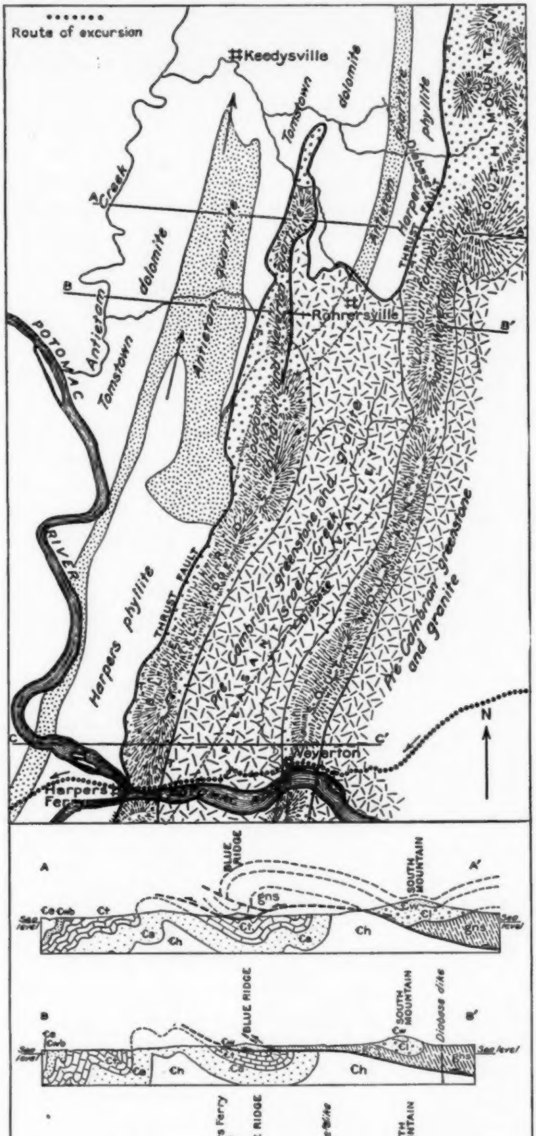
FIG. 1.—Physiographic diagram of eastern United States, showing Piedmont mountainous tract, Valley province, Allegheny Front, and Appalachian Plateau province. (After A. K. Lobeck, 1932.)

stratigraphy and the structure of the area as it appears today. Fortunately the amount of information is now very great, thanks to the efforts of the United States Geological Survey and various members of State surveys. Many of the early folios of the United States Geological Survey describe portions of the area in which the most critical data are contained.

Subdivisions of area.—For purposes of discussion it is convenient to subdivide the Appalachian province into three subdivisions and briefly enumerate the characteristics of each. The names used by physiographers are perhaps best adapted and will be used with slight modifications. These are the Piedmont Plateau, the Valley province, and the Appalachian Plateau province (Fig. 1).

Stratigraphy of Piedmont province.—The Piedmont province as classified in this paper extends from the Blue Ridge Mountain, eastward toward the Atlantic to the Cretaceous overlap. It is made up of pre-Cambrian rocks almost entirely, but here and there small remnants of Cambrian as well as Ordovician sediments have been preserved. In southeastern Pennsylvania for example, east of the continuation of the Blue Ridge (there called South Mountain) such rocks are found for a distance of 36 miles. In Virginia the Quantico slate, thought to be of Ordovician age, lies 55 miles east of the Blue Ridge. Long narrow strips of Cambrian sandstones and thin Ordovician limestones appear along the Catoctin fault approximately 30 to 48 miles east of the Blue Ridge. Farther south is the Arvonia slate area, 36 miles east of the Blue Ridge. In western North Carolina, the mountainous tract corresponding with the Blue Ridge is wider and consists, in large part, of thick Cambrian sandstones and arkoses. Small patches of the same rocks are preserved considerably east of the western escarpment like those near Newland, North Carolina, and east of Talladega, Alabama. The pre-Cambrian rocks are gneisses and schists mostly, which show prominent evidences of metamorphism. Large areas are occupied by Carboniferous intrusive igneous rocks. Smaller areas consist of Triassic sediments and Triassic intrusive rocks.

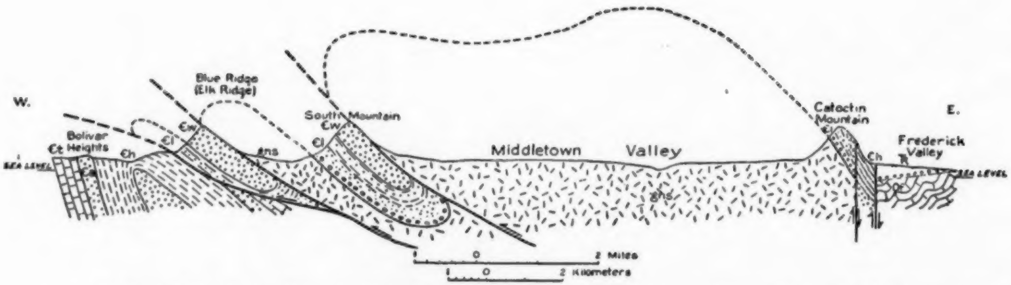
Structure.—The rocks of the Piedmont are strongly folded and faulted. At the western margin is a zone of great overthrusting. The Blue Ridge border thrust fault can be traced from South Mountain in Pennsylvania through Harpers Ferry, West Virginia, southwestward through Roanoke, Virginia (Figs. 2, 3 and 4). It leaves Virginia about at longitude 81° 45′ near Damascus and trends southwestward almost on the boundary line between North Carolina and Tennessee. Thence it may be traced through northwestern Georgia and into Alabama east



GEOLOGIC MAP AND SECTIONS, AREA NORTHEAST OF HARPERS FERRY, WEST VIRGINIA

Ꞓe, Elbrook limestone; Ꞓwb, Waynesboro formation; Ꞓt, Tomstown dolomite; Ꞓa, Antietam quartzite; Ꞓh, Harpers phyllite; Ꞓw, Weverton quartzite; Ꞓl, Loudoun formation; gns, pre-Cambrian greenstone; gr, pre-Cambrian granite.

FIG. 2.—Detail map showing structure along west side of Piedmont province. Note strongly developed overthrusts. (From *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)



Section of Blue Ridge-Catoctin Mountain anticlinorium. ℞, Triassic sandstone; Of, Frederick limestone; Ꞓt, Tomstown dolomite; Ꞓa, Antietam quartzite; Ꞓh, Harpers phyllite; Ꞓw, Weverton quartzite; Ꞓl, Loudoun formation; gns, pre-Cambrian greenstone

FIG. 3.—Detail along west side of Piedmont province, showing overthrusts in Blue Ridge area, normal faults in Catoctin area and Triassic geosyncline. (From *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)

of Talladega and west of Ashland. The great persistence of this overthrust fault and its great length have a special significance which will be brought out later. Closely paralleling this fault are several belts of normal faults within the Piedmont and farther southeast. One of these has been named the Catoctin border fault. It can be traced from Leesburg in northern Virginia southwestward with minor interruptions and change in trend through Charlottesville. It leaves the state west of Stuart in Patrick County (80°40′) and enters North Carolina east of Sparta from where it strikes southwestward to the corner made by the Carolinas and Georgia. Another similar fault may be traced from Chatham, Virginia, through North Carolina and well into South Carolina. It is significant that the long narrow belts of Triassic sediments are intimately associated with these fault zones.

Appalachian Valley province.—The Valley province (sometimes referred to as the Valley and Ridge province) lies northwest of the Piedmont. It varies in width from 72 miles in south-central Pennsylvania to 55 miles in northern Virginia, to 36 miles in central Virginia, and widens to 40 miles in southern Virginia, 60 miles in eastern Tennessee, and 56 miles in southern Tennessee and adjacent Georgia. The rocks in this province belong chiefly to the Cambrian, Ordovician, Silurian, Devonian and Mississippian systems. At the south end (in northwestern Georgia and eastern Alabama) Pennsylvanian rocks (only Pottsville) encroach upon the area of this province. Farther north the eroded edge of these rocks forms a prominent escarpment which is called the Cumberland escarpment in Tennessee and Virginia, and the Allegheny Front elsewhere. Physiographically this prominent feature marks the western side of the Valley province.

Structure of the Valley.—Since the structure of the Valley is of great importance in deciphering the history of the geosyncline a number of cross sections are included to elucidate the peculiarities enumerated later. These are shown in Figures 5, 6, 7, and 8. They reveal the fact that anticlines are the dominant or primary feature and that synclines are subordinate or secondary. They also reveal the fact that many anticlines are overturned toward the west and that most of them have the steeper dips on the west side. Finally it appears that many anticlines are ruptured by thrust faults which almost invariably dip to the southeast at relatively steep angles. Since the portions of the Valley characterized by faults and those characterized by unbroken folds have been sharply differentiated in all previous discussions of the Appalachian region it will be profitable to list some statistics on this point. These data are compiled from the various state maps in the area and many of the folios published by the United States Geological Survey.

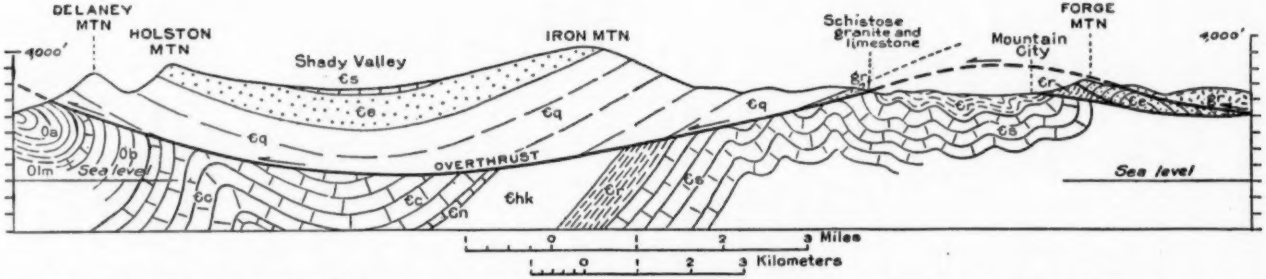


FIG. 4.—Detail along west side of Piedmont to show overthrusting in southern Virginia. (Plate 26, *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)

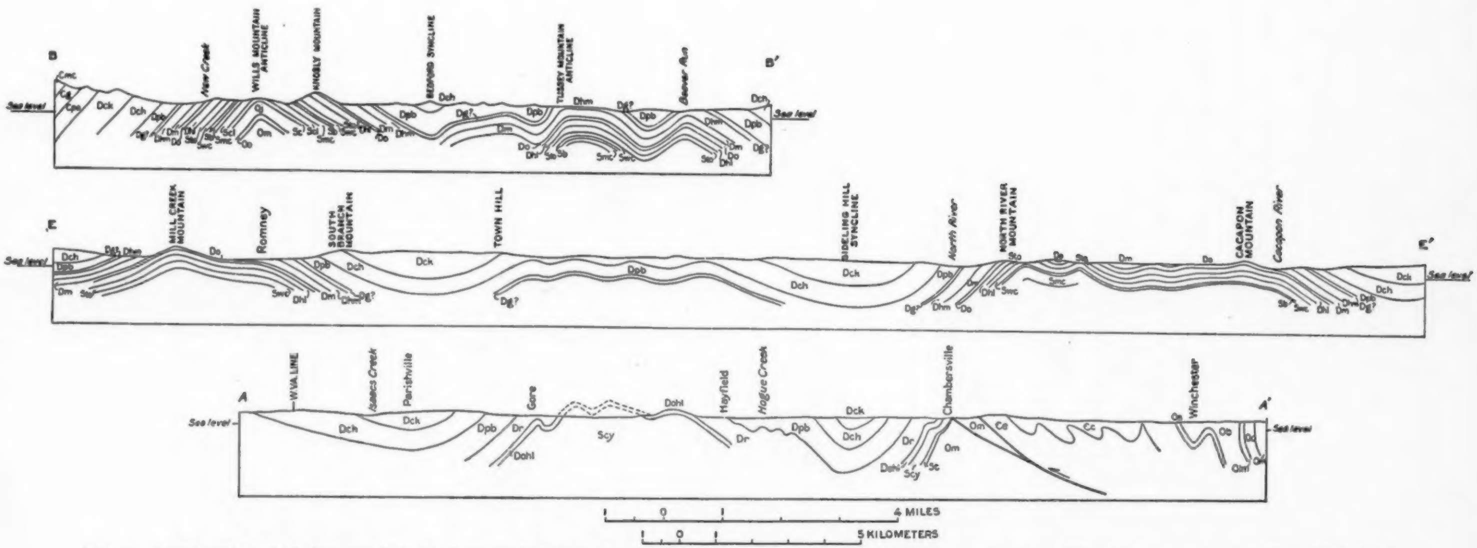


FIG. 5.—Cross section of Valley province to show typical area of open folding, from Keyser, West Virginia, eastward to Winchester, along north line of Virginia. *BB'* on west; *EE'* center; *AA'* on east. (Plates 11 and 12, *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)

A typical cross section for Pennsylvania (prepared by G. W. Stose) appears on the latest geological map of that state. Between the Allegheny Front and the Blue Ridge (South Mountain), a distance of 72 miles, there are seven anticlines. Four of these are broken by thrust faults. The striking thing about these is the fact that intensity of deformation is not related to distance from the Blue Ridge as might be expected. The westernmost anticline (Roaring Spring anticline) is as high as, or higher than, any of those farther east. The second from the west (Tussey Mountain) is thrust-faulted allowing the Beekmantown (Lower Ordovician) limestone to appear at the surface. Between the second and the fifth anticlines lies the Broadtop coal field syn-

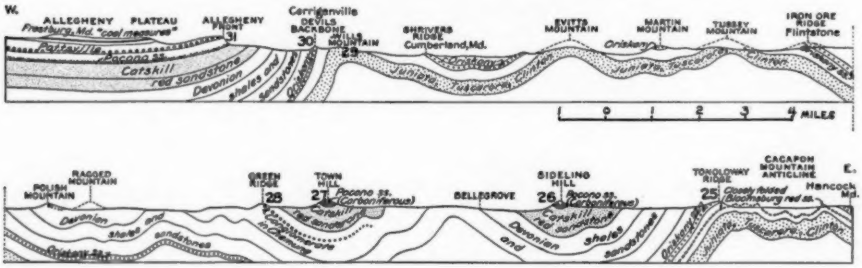


FIG. 6.—Detail of structure at junction of Plateau province and Valley province. Notice steep overturned fold at 29, broad synclinorium between 28 and 29 and steep west dip at 25. (From *Sixteenth Inter. Geol. Cong. Guidebook No. 3*, 1933.)

clinorium which is very broad and relatively flat when compared with the up-arched areas. East of it lies the McConnellsburg thrust fault in which Beekmantown strata come to rest adjacent to Upper Devonian shales.

West Virginia and Virginia.—The city of Keyser, West Virginia, lies at the edge of the Allegheny Front and just west of the Wills Mountain anticline. A cross section southeastward across the strike is shown in Figure 5 and extends across the northern part of Virginia to a point near Winchester. It shows nine anticlinal flexures, one of which is thrust-faulted. The same lack of correspondence between intensity of deformation and distance from the Blue Ridge is again manifest, for Wills Mountain anticline is as high as, or higher than, any of the others, with the possible exception of those near the eastern side. It will also be noted that the synclinal areas are broader and flatter than the anticlinal areas. In order to bring out these characteristics Figure 6 has been added. It shows approximately two thirds the same distance as Figure 5 and lies a few miles farther north.

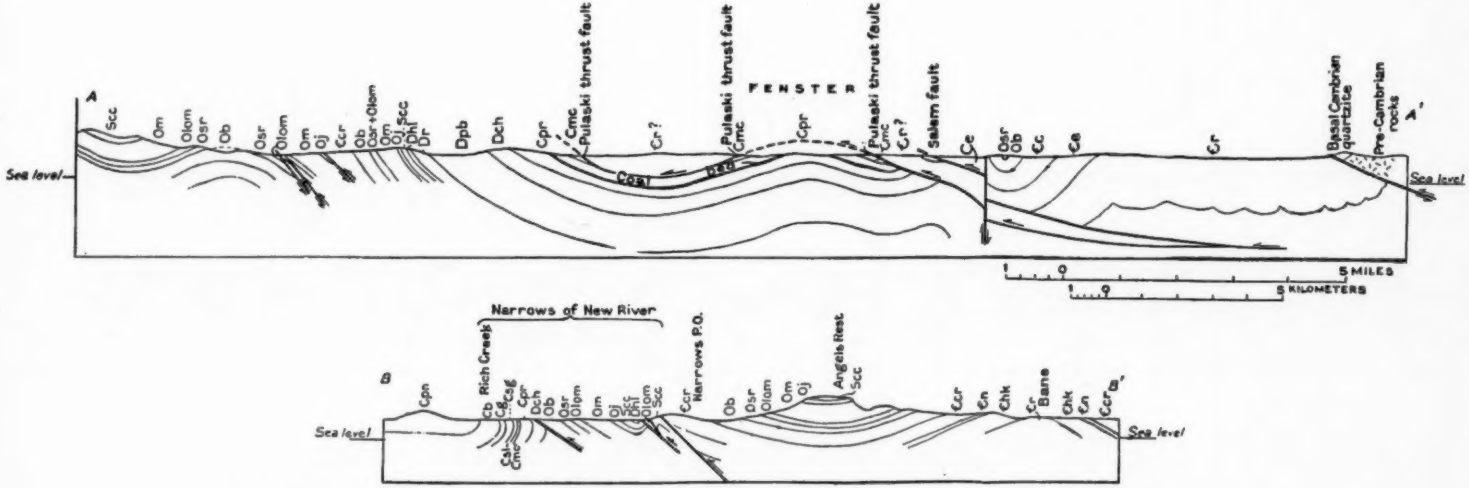


FIG. 7.—Detail of structure in Valley province, showing shingle structure and overthrust sheets. Southwest Virginia from Glenlyn to Christiansburg. *BB′* lies west of *AA′*. (Plate 19, *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)

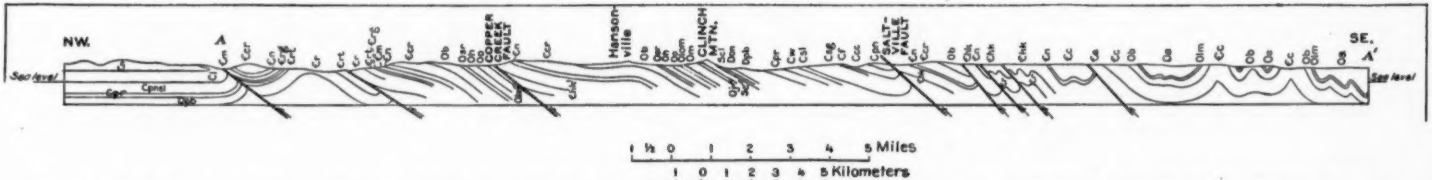


Fig. 8.—Typical cross section in southern Virginia to show shingle structure in area of numerous thrust faults. (Plate 21, *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)

Eighteen cross sections across the Valley are shown on the map of the Appalachian Valley in Virginia prepared in 1933 by Butts and Stose. Inasmuch as the Valley reaches over into the state of West Virginia at a number of points these cross sections are not exactly comparable. By adding the corresponding data from the West Virginia map the following structural features are brought out by them. The number of anticlines varies from nine at the north to approximately 11 at the south (through Wytheville). Only one is broken by a thrust fault at the north. Toward the south the number of thrusts increases until 10 of the 11 anticlines in the Wytheville cross section are affected.

Cumberland thrust block.—Southwest of the Wytheville cross section a somewhat exceptional complication is introduced by the Cumberland overthrust block. This was first mapped by Keith when he surveyed the Briceville Quadrangle in Tennessee and is beautifully shown in the United States Geological Survey *Folio 33*. Later work by Wentworth and others showed its northward extent into Kentucky and southwestern Virginia. It is also shown on the most recent geologic map of the United States published in 1932. Figure 9 shows that the block is 25 miles wide and 120 miles long. The accompanying cross section shows the Pine Mountain fault as the western boundary in Kentucky and the Hunter Valley thrust fault as the southeastern boundary. The rather intense deformation of the rocks along the Russell Fork fault on the northeast and the Jacksboro fault on the southwest is ample evidence of horizontal movement.

Tennessee and Georgia.—In northern Tennessee a cross section from the northwest corner of the Nantahala Quadrangle, northwestward across the Loudon Quadrangle, in a width of 44 miles, reveals 15 anticlines of which 13 are broken by thrust faults. Farther south a similar cross section from the northwest corner of the Ellijay Quadrangle, northwestward across the Cleveland Quadrangle and partly into the Chattanooga Quadrangle, in a distance of 42 miles, shows 16 anticlines of which 11 are thrust faulted.

Appalachian Plateau.—The Appalachian Plateau belt is beautifully shown on the physiographic diagram of the United States made by A. K. Lobeck (Fig. 1). It occupies most of western Pennsylvania and eastern Ohio where it has a width of 225 miles. Thence it extends southward through West Virginia and eastern Kentucky. Across this distance it averages 150 miles in width. Where it enters Tennessee it has a width of only 35 miles and becomes even narrower as it passes across the northwest corner of Georgia and enters northeastern Alabama.

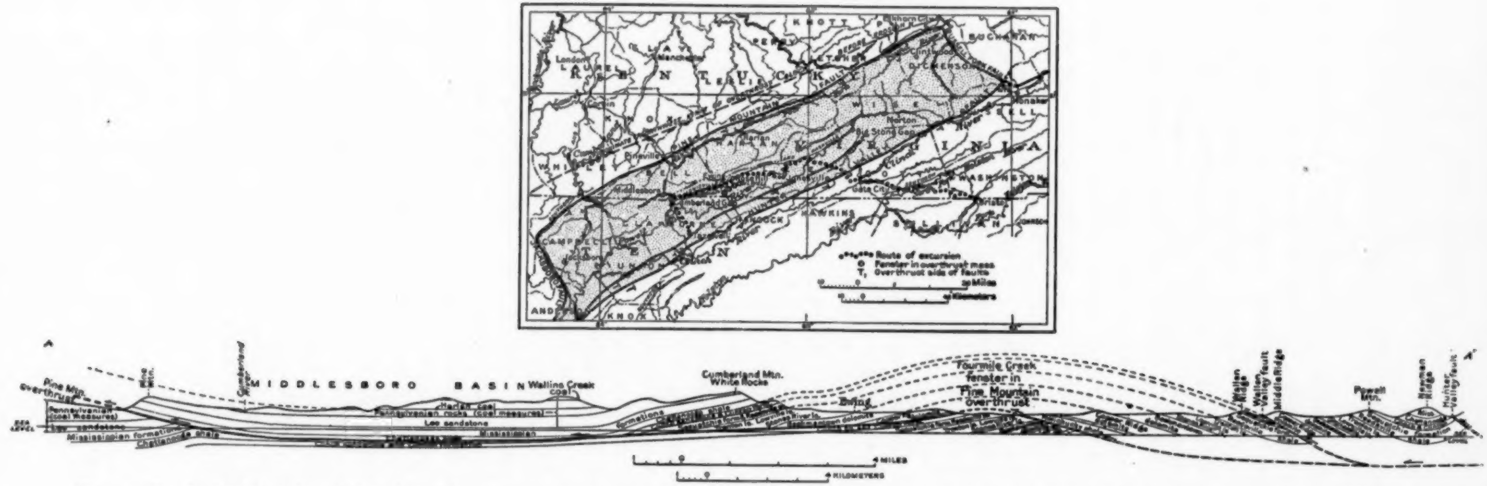


FIG. 9.—Cumberland overthrust block in southwest Virginia and adjacent states. Areal map and cross section. (From *Sixteenth Inter. Geol. Cong. Guidebook No. 3.*)

The rocks in this province belong mostly to the Pennsylvanian system. The exceptions are the Permian area centering around the southwestern corner of the state of Pennsylvania and some narrow belts of older rocks in southeastern Kentucky along the Pine Mountain fault, and in Tennessee and Alabama along the Sequatchie Valley. Only the oldest division of the Pennsylvanian (Pottsville) is represented south of the Cumberland overthrust block. Farther north the younger divisions (Allegheny, Conemaugh, and Monongahela) appear one after the other until the Permian area is reached.

Plateau structure.—At present the structure of the northern Plateau province is that of a great basin having its deepest part in the Permian area. The axis marking the deepest portion passes nearly through the southwestern corner of Pennsylvania, thence through West Virginia in a southwesterly direction and into eastern Kentucky with a nearly east and west trend, toward the Cumberland saddle. The basin is modified by a limited number of long narrow anticlinal folds between which lie broad synclinal tracts. If due allowance is made for small offsets and saddles across their trend, the anticlinal folds can be traced for long distances and show a striking parallelism with the folds in the Valley province.

In Pennsylvania a typical cross section prepared for the latest state map by G. W. Stose shows six anticlines in a distance of 105 miles. In a general way these anticlines are very low and subdued in the west and higher toward the east. Specifically, however, the easternmost two stand out much more prominently than the others. These two are the famous Chestnut Ridge and Laurel Hill anticlines. When traced southward the Chestnut Ridge anticline becomes lower and more subdued, but can be traced southwestward across West Virginia along the trend of the Hansford and the Warfield anticlines. The Laurel Hill anticline remains high and prominent for a long distance into West Virginia where it is called the Deer Park anticline on the latest state geological map. It dies out in northern Pocahontas County, but another lower anticline resumes on nearly the same trend farther southwest (Boggs Knob anticline). In West Virginia two other anticlines wedge in between the Laurel Hill-Deer Park trend and the Roaring Spring-Wills Mountain trend which marks the western border of the Valley province. Their disappearance to the south indicates a convergence of trend lines in this part of the basin. They seem to pass downward and under the St. Clair fault in Monroe County.

The St. Clair is the westernmost of a great cluster of thrust faults in southwestern Virginia and foreshadows the influence of the struc-

tural peculiarity climaxed by the Cumberland overthrust block. The border between the Valley province and the Plateau province is completely masked by this overthrust block. When the area south of the block is examined an interesting situation is noted. The Cumberland escarpment is prominent in the Briceville, Kingston, and Chattanooga quadrangles. High anticlines with steep west slopes (or thrust faults) on the west lie directly east of the escarpment. To the west folding is practically absent for a distance of 18 miles until the Sequatchie valley is reached. There a typical, high, overturned (or thrust faulted) anticline appears. This can be traced continuously across parts of six quadrangles (Kingston, Pikeville, Chattanooga, Sewanee, Stevenson, and Gadsden). Its relatively isolated position, nearly straight trend, and long extent are significant features. Furthermore it lies almost exactly on the projected trend of the Pine Mountain fault, at the northwest side of the Cumberland block.

Original geosyncline.—The area and extent of the pre-Cambrian geosyncline are shrouded in obscurity. Some data might be adduced by platting the distribution of Algonkian rocks, but the great amount of deformation, metamorphism, and erosion, to which they have been subjected, makes the problem exceedingly difficult and the conclusions highly speculative. Beginning with Cambrian time, however, changes were less destructive and all the evidence has not been obliterated. By platting the distribution of Cambrian strata as now known, it is possible to deduce that the shoreline lay at least as far southeast on the Piedmont as the Catoctin fault. Reference to the State maps of Virginia and Pennsylvania reveals long narrow strips of Lower Cambrian rocks preserved on the downthrown side of the fault. Since the zone of faults had a great throw toward the southeast, considerable thicknesses of strata are now available for study. Incidentally it is important to note that the same movement along the same faults in Triassic time allowed thick wedges of fanglomerates to accumulate on the Piedmont.

The geologic map of Virginia shows that only early Cambrian sediments are preserved east of the great Blue Ridge thrust fault. In Pennsylvania, on the other hand, rocks of the same age as well as those of Upper and Middle Cambrian age are preserved in the York, Lancaster, and Chester valleys in the southeastern part of the state. Here also strips of Ordovician rocks up to and including the Upper Ordovician Martinsburg are preserved. In Virginia, Ordovician rocks in very small patches are preserved as far east as Stafford near the Potomac River (Quantico slate) and Arvonia farther southwest. These points lie 20 and 15 miles, respectively, east of the present easternmost

Cambrian remnants. Farther south in the Great Smoky Mountains along the boundary between North Carolina and Tennessee, Lower Cambrian rocks extend a number of miles east from the Blue Ridge overthrust which borders the Piedmont on the northwest side. It is important to note that they are intimately associated with thrust faults closely parallel with the Blue Ridge border fault.

The assumption is valid therefore, that Cambrian and Ordovician sedimentation extended at least as far east as the points mentioned.

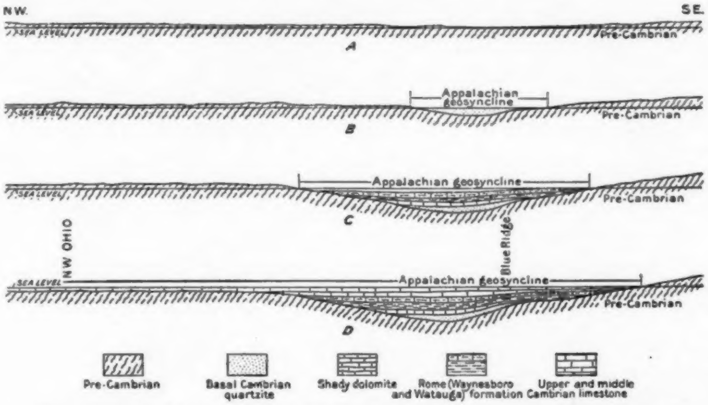


FIG. 10.—Usual interpretation of axis of subsidence in Appalachian geosyncline. Hypothetical sections across Appalachian geosyncline to show progressive subsidence, probable location of axis of subsidence, and transgression and overlap of younger deposits outward from axis. *A*, at beginning of Cambrian time; *B*, at the end of Antietam time; *C*, at end of Rome (Waynesboro) time; *D*, at end of Upper Cambrian time. (From *Sixteenth Inter. Geol. Cong. Guidebook No. 3*, 1933.)

The coarseness of the Cambrian materials indicates that, in Cambrian time at least, the landmass of Appalachia was located only a few miles farther southeast. Figure 10, no doubt, represents the conception of most geologists of the nature of the Cambrian geosyncline. The map prepared by the writer (Fig. 11) showing the thickness and distribution of Cambrian sediments suggests another probability. It will be noted that the sediments thicken toward the east in the direction of ancient Appalachia. To this all writers on the stratigraphy of the Appalachian region agree. A maximum of 20,000 feet is recorded in southeastern Tennessee and comparably great thicknesses in near-by quadrangles.[3]

[3] For details the reader is referred to the writer's article: W. A. Ver Wiebe, "Thickness and Distribution of Paleozoic Sediments," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 495 ff.

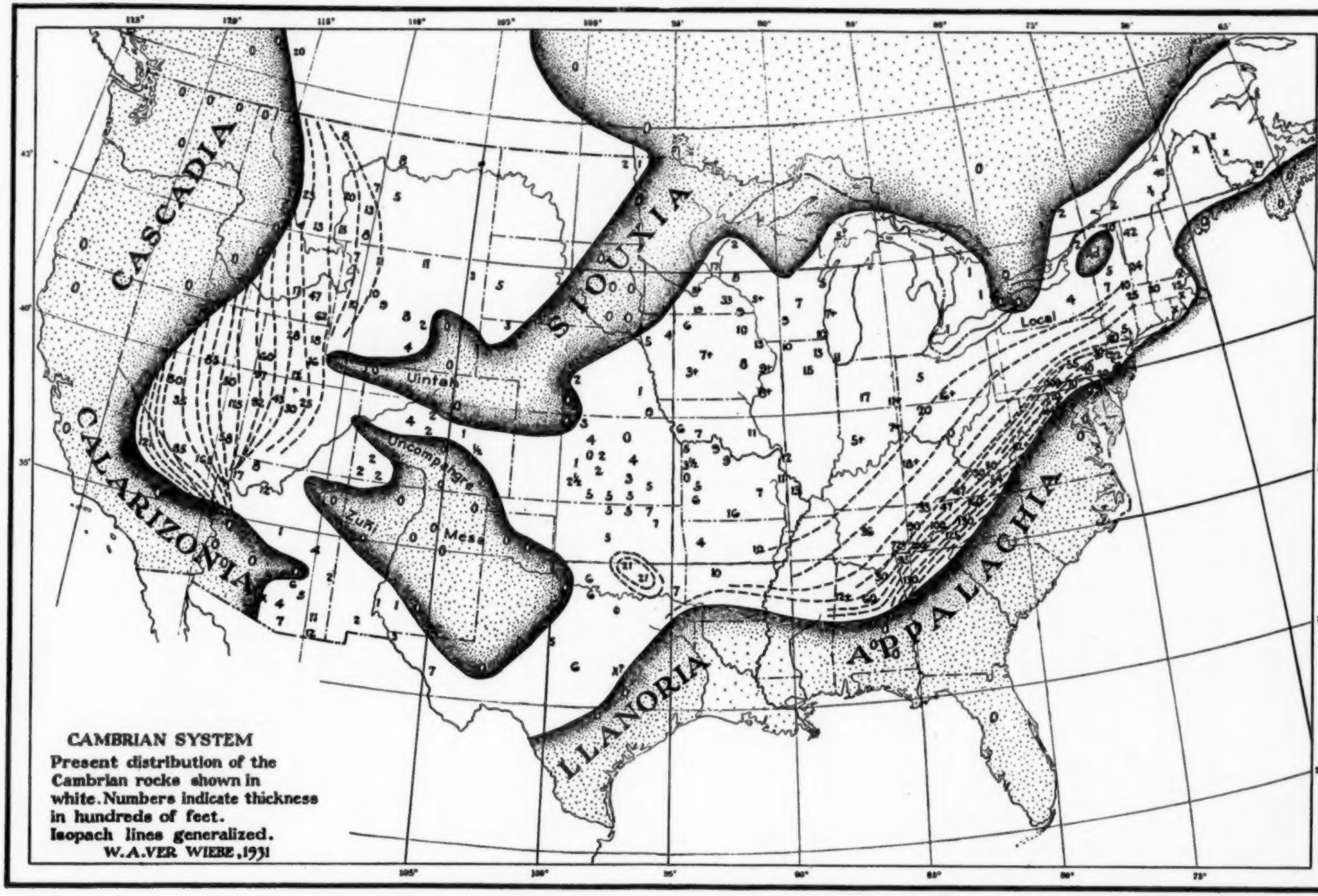


FIG. 11.—Map showing thickness of Cambrian rocks in the United States.

It is difficult to conceive of the deposition of such great quantities of coarse arkoses, gravels and sands as constitute the Cambrian in this part of the geosyncline without assuming a fault between the landmass and the deepest part of the geosyncline. The nature of the material, the enormous thickness and the evidence of continued sinking demand the postulation of a shear zone of weakness immediately adjacent to the sediments. The writer believes that this shear zone was inherited from pre-Cambrian time and was probably originally a normal fault. A striking parallel is provided in the Triassic boundary faults which are still preserved on the Piedmont in Virginia and other states and along one side of which truly remarkable accumulations of sediments have been found.[4] A close parallel is also provided in the evolution of the Rocky Mountains[5] in which a rapidly rising block of the earth's crust shed Tertiary arkoses and conglomerates toward the east (Fig. 12).

It is further presumed that this great "Boundary fault" was not a continuous fault along the west side of Appalachia. More probably it was a zone of faults arranged more or less *en échelon*. This is indicated by the rather notable variations in thickness as shown on the map—Figure 11—and Table I. It is also indicated by fault patterns of more recent age, such as those of California and eastern Africa or the Catoctin belt of faults. Furthermore, the throw was no doubt variable from point to point along the zone involved. We may assume that it reached one of its maxima in the region of the present Great Smoky Mountains. Another maximum is indicated in southeastern Pennsylvania.

Silurian geosyncline.—A study of the present distribution of Silurian rocks and their thickness[6] indicates that the eastern border of the present remnants of this system lies a short distance west of the Cambro-Ordovician remnants. Certain evidence, however, indicates that most of the differences are accounted for by erosion subsequent to the time of deformation. The same may be said about the sediments of all later systems with the exception of the Permian system. It appears that the great boundary fault of the Appalachian geosyncline maintained its approximate position until at least Pottsville time.

Depth of geosyncline.—It is not a simple matter to determine the depth of the geosyncline. The Appalachian revolution affected the rocks in the eastern part of the geosyncline most violently and lifted

[4] J. K. Roberts, *Virginia Geol. Survey Bull. 29* (1929).

[5] W. A. Ver Wiebe, *Historical Geology*, 2nd ed. (1936), p. 69.

[6] W. A. Ver Wiebe, "Thickness and Distribution of Paleozoic Sediments," *Bull. Geol. Soc. America*, Vol. 43 (1932), p. 510.

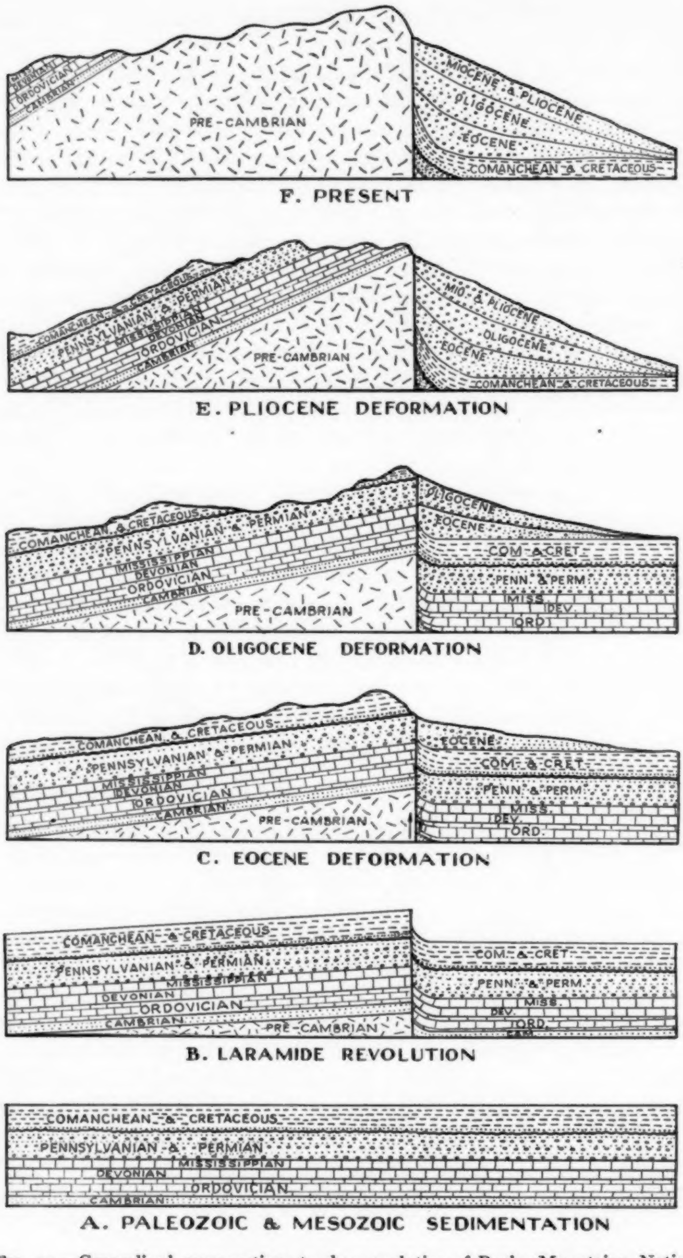


FIG. 12.—Generalized cross sections to show evolution of Rocky Mountains. Notice boundary fault and zone of thickest and coarsest sediments to east.

them into highest relief. Therefore most of the sedimentary column has been removed in the region of greatest subsidence. The most satisfactory measurements are available in northeastern Pennsylvania and in Alabama. In the anthracite district Pottsville rocks have been preserved and can be measured closely adjacent to highly deformed anticlines. Pennsylvania State Survey reports indicate a thickness of slightly over 23,000 feet in Carbon County and nearly 20,000 on the same trend in Perry County. These thicknesses do not take into account the Middle Ordovician or older rocks. In Alabama where the Pottsville rocks rest directly on, or closely adjacent to, much older rocks the total thickness is 17,300 feet. Other points between these two end points are given in Table I. The largest totals appear where the Cambrian rocks are thickest. Caution should be used in comparing these figures. They represent the average thickness across a whole quadrangle and do not indicate the thickness at given points. Also, exact thicknesses are not possible on account of deformation. Furthermore, all systems are not included in all cases and in some, the full thickness of the upper or lower system is not known. It is doubtless safe to say that the geosyncline exceeded 20,000 feet at the time of maximum subsidence and may have reached 25,000 at favored spots. The remarkable feature brought out by the table is that the maximum is approximately 22,000 feet throughout the length of the area..

Deformation and sedimentation.—A comparison of thicknesses in many parts of the geosyncline, in addition to those already given, shows that there is great variation in each system. This indicates that from time to time the points of rapid subsidence varied in position along the boundary fault. Furthermore, there is evidence of rapid changes in thickness along lines parallel to the axis of the geosyncline. These facts have been noted and emphasized by others, especially Ulrich, Butts, Willis, Keith, and Schuchert. These geologists postulate gentle upwarps of the geosyncline floor to produce separate basins of deposition. Those who are interested in this phase of the subject will find especially illuminating material in the United States Geological Survey *Folio No. 221* on the Bessimer-Vandiver Quadrangle in Alabama. Butts has differentiated three basins of deposition in which the stratigraphic sequence differs strikingly. Marked hiatuses in the sequences and prominent unconformities—as for instance below the Attala conglomerate—point to deformative movements in the basement rocks.

It is, therefore, logical to assume that a number of faults existed in the pre-Cambrian basement at the time the great boundary fault was formed. Studies of faulted areas in many parts of the world

TABLE I
THICKNESS OF SEDIMENTS IN GEOSYNCLINE

	New Jersey Folio 161	*Pennsylvania Folio 170*	*Maryland Folio 179*	*Virginia Folio 44*	*Virginia Folio 12*	*Tennessee Folio 118*	*Tennessee Folio 16*	*Tennessee Folio 25*	*Georgia Folio 78*	*Alabama Folio 221*
PENNSYLVANIAN				2700	5000			1200+	400+	7300
MISSISSIPPIAN			1950	4500	2600	1600+	600+	1100	3500	1200
DEVONIAN	2000	1800+	11,000	3500	2000	1600	1200	1200	1200	20
SILURIAN	2000	1800	1950	1100	1100	1200	1100	2000	1500	250
ORDOVICIAN	4000	6000	2400	4000	4200	6500	8300	6800	7500	6000
CAMBRIAN	2000	10,000	1200+	3000	4700	12,000	10,000	10,000	13,000	2600+
TOTAL	10,000+	19,600+	18,500+	18,800	19,600	21,900+	21,200+	22,300	27,100	17,370

indicate that faults seldom appear singly. Very commonly they appear in zones of subparallel arrangement. Vertical movement along the faults in the basement rocks under the Paleozoic sediments caused

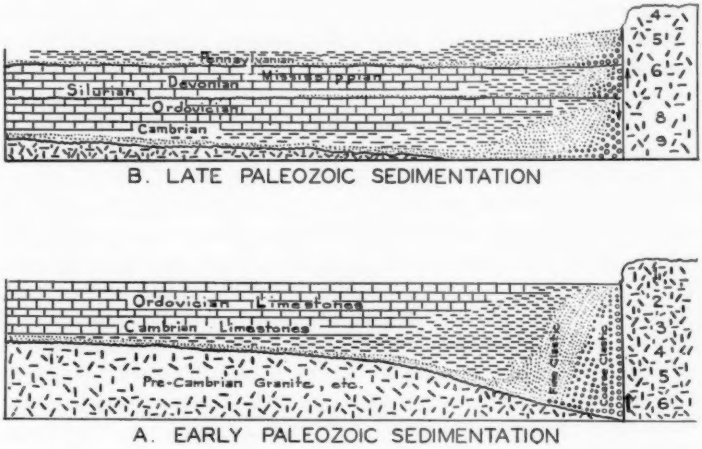


FIG. 13.—Hypothetical restoration of Appalachian geosyncline (*A*) during early Paleozoic time and (*B*) during late Paleozoic time. Notice stripping off of segments from landmass of Appalachia and eastward encroachment of limestone with reduction of landmass.

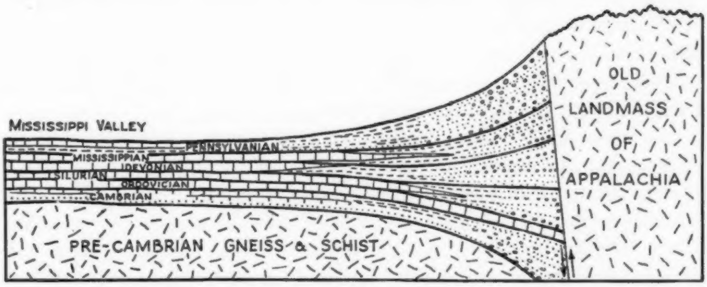


FIG. 14.—Hypothetical restoration of Appalachian region before Appalachian revolution. Notice boundary fault on west side of Appalachia and variation of sediments and change in thickness.

initial anticlines to form. These anticlines later formed the foci of renewed upward thrusts culminating in the great deformative movements of the Appalachian revolution.

Cause of deformation.—Beginning with the efforts of the Rogers brothers early in the last century many geologists have attempted to explain the peculiar rhythmic arrangement of the folds in the Appalachian region. The classic experiments of Willis are known to all. His general summary[7] is a veritable mine of information and the reader will find practically all peculiarities and characteristics of the deformed area described and elucidated therein. His experiments were conducted on an elaborate scale and brought out many valuable data on the mechanism and mechanics of earth deformation. In the early part of his work he states that he was "embarrassed to explain the constant occurrence of an anticline at the end of the model nearest the piston. . . ."[8] This result came after he had considered nearly all possible factors involved in the experiment so as to reproduce the Appalachian folds as fáithfully as possible. These factors included a study of the crushing strength of the rocks, the modifying influence of depth and temperature, the variations in competency, flexibility, and frangibility, the effects of loading, et cetera. His conclusion finally reached, and one that guided him to the very last, was that the thick Cambro-Ordovician limestone sequence would transmit a horizontal thrust from the east, that it would depress synclines and raise all upward curves into anticlines. This conclusion has not been challenged by later writers.

He furthermore concluded that the reason for the many thrust faults in the southern part of the Valley province and the predominance of open folding farther north was due to different stratigraphic sections involving the thick Cambro-Ordovician limestones at two different levels in the sequence. This idea was elaborated upon especially by Keith in his masterful summary of mountain structure. It has also been accepted by other writers.

In order to overcome the awkward result of producing a single anticline at one end of his model Willis decided to introduce a slight change in dip of the strata. Many experiments made later with variations in initial dip at various points still did not seem to eliminate the main difficulty, however, for his illustrations in Plates 79 to 92 fail to reveal proper multiples of folds and their rhythmic arrangement as found in nature. In his final summary Willis indicated that he believed the arrangement to be due to the redistribution of weight when one competent anticline, by transfer of load to the area beyond, caused an initial dip to form there.

Age of folding.—It has been commonly assumed that the Ap-

[7] Bailey Willis, *U. S. Geol. Survey 13th Ann. Rept.*, Pt. II (1893), pp. 217 ff.

[8] Bailey Willis, *op. cit.*, p. 243.

palachian revolution took place after the Permian sediments were laid down. There is no proof of this fact, however. The Permian strata now appear in three states bordering on the southwestern corner of Pennsylvania. In this area the folding is so subdued that folds are difficult to map. The difference in structural relief of this area when compared to the plateau area farther east is well shown by Richardson.[9] The writer believes that the history of the Appalachian Mountains will be found to correspond to that of the Arbuckle-Ouachita region when all pertinent facts are available. In that part of the continent definite proof of orogeny may be adduced from the stratigraphic record. Violent movements took place in early Pennsylvanian time (post-Springer or Bend) and again in late Pennsylvanian time (post-Hoxbar and pre-Pontotoc). The zone of violent deformation was narrow in each case and moved outward from the hinterland in time. Evidences of both orogenies are detected as far north as Kansas and Nebraska. Similarly, the Appalachian geanticlinal region (at the border of the Piedmont) was in all probability affected by violent movements at these two critical times. In this case the evidence consists of the coarse Pennsylvanian sediments resulting from the movements and secondly the marked differences in stratigraphic sequences in northeastern Alabama. The mild folding of strata noted in the Permian area of northwestern West Virginia is duplicated by similar mild folds in the Permian rocks of Oklahoma and Kansas.

Cause of folding.—If the existence of the great zone of boundary faults at the west side of Appalachia is granted and if it is admitted that sub-parallel faults existed in the basement complex under the geosyncline, then certain conclusions follow which explain the Appalachian folds and thrust faults in a new manner. The basement rocks consist, for the most part, of massive granites and their metamorphic equivalents. Since they are immensely thick and very nearly homogeneous they will resist deformation much better than the overlying sediments. It also follows that they will act as a rigid strut and transmit horizontal pressure much better than the overlyingsediments.

The evidence for horizontal pressure against the east side of the Appalachian region is convincing. The evidence, furthermore, indicates that this pressure operated more or less continuously throughout Paleozoic time. The periods of sudden adjustment to stress have been enumerated by Keith[10] to which other authors generally agreed.

[9] Richardson, "Structure-Contour Maps of the Pittsburgh-Huntington Basin," *Bull. Geol. Soc. America*, Vol. 39 (1928), Pls. 2 and 3.

[10] Arthur Keith, "Structural Symmetry in North America," *Bull. Geol. Soc. America*, Vol. 39 (1928), p. 385.

They need not be repeated here. The most violent pulsations probably came during Carboniferous time and it is probable that two pulsations are indicated by the present differences in structure. The strongly deformed Valley zone appears to reflect the effects of the early Pennsylvanian orogeny; and the more gently deformed Pennsylvanian rocks of the Plateau zone, the effects of the late Pennsylvanian orogeny.

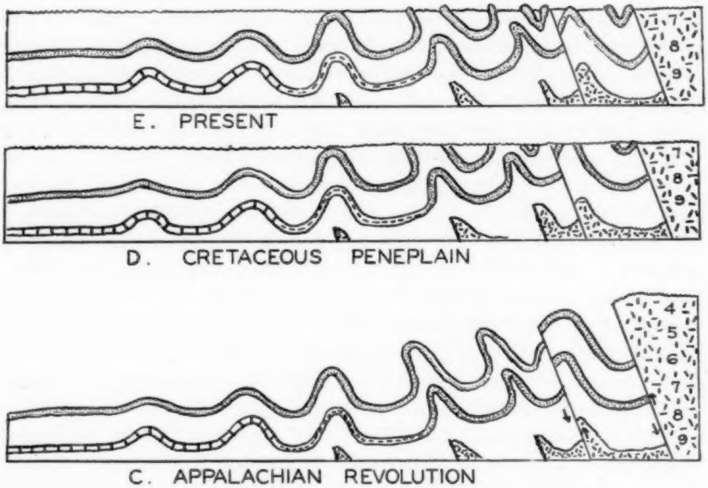


FIG. 15.—Hypothetical restoration of Appalachian Mountains during Pennsylvanian time. Note effect of foundation faults on anticlines. In *D*, Cretaceous peneplain, notice elimination of high eastern folds and upper part of Appalachia. *E*, Present, shows etching into relief of resistant layers to form present mountain ridges.

Buried fault-block theory.—The mechanics of the deformation as interpreted by the writer are as follows. A tangential compressive stress was initiated from a southeasterly direction. It began as a nonrotational stress and the plane of maximum intensity lay deep within the crust at a depth exceeding the maximum depth of the geosyncline. The stress was transmitted through strong, massive and rigid rocks of nearly homogeneous character. Under these conditions the normal component would be large and the shearing component small. Nevertheless since the direction of easiest relief would be upward, rupture would occur and take the form of high-angle faults inclined toward the southeast. The writer believes, however, as outlined in previous pages that lines of weakness in the pre-Cambrian foundation

existed. These were normal faults more or less parallel to the boundary fault zone of the geosyncline. They became shear planes allowing segments to move upward. With continued application of stress from the southeast the tangential component became dominant and the fault blocks lifted the overlying sediments into initial anticlines. Since the thrust was operative early in the history of the geosyncline (certainly as early as Lower Ordovician time) the overburden was not excessive.

Since many faults were involved, the early deformation would resemble the imbricate structure so well known from the Scottish Highlands. Since the application of force was deep-seated it could be transmitted to distant points from the main boundary fault. In fact, some of the more distant faults might cause greater displacement than those nearer the southeast. Since the deforming force acted slowly, the resulting folds above the faults were low and symmetrical during most of Paleozoic time. In Pennsylvanian time, however, the force was applied more violently in the area of the geosyncline, and the folds therefore became high and were overturned in a direction away from the thrust (Fig. 15).

The writer believes that this explanation fits the observed conditions better than any previous one. It explains why there are many anticlines in long, sub-parallel trends. It explains why some are higher to the west than would normally be expected, as, for instance, the zone extending from the Nittany arch in Pennsylvania through Wills Mountain anticline, etc. It also explains why the synclines appear as passive features in broad, gently deformed areas between the positive, strongly arched anticlines. It furthermore offers a reasonable explanation for such eccentrically located structures as the Volcano-Burning Springs anticline in northwestern West Virginia and smaller cross folds southeast of it. It may explain the two cross-faults limiting the Cumberland overthrust block.

Faulted areas versus folded areas.—As pointed out previously in this paper, many authors have tried to explain the pronounced increase in thrust faults in southern Virginia and adjacent parts of the Valley province. An examination of the geological map of the United States reveals the fact that the zone of prominent faults lies between the Carolina salient and the two prominent domes on the Cincinnati arch—the Nashville dome and the Jessamine dome. The writer believes that the line of up-arching usually referred to as the Cincinnati arch marks the location of one of the early initial anticlines and was probably pushed high during Ordovician time. The presence of a large mass of basement rocks in this zone served as a buttress and offered passive resistance to the active thrust from the east. Since the space

was thus narrowed, the slices of basement rock were forced upward at a steeper angle than in the area to then orth. Furthermore, they were crowded closer together. The result was a zone of anticlines (nearly all of which are thrust-faulted on the west) and a number of low-angle overthrust sheets.

That the same situation existed locally in West Virginia and in Pennsylvania is proved by the excessive height of some western anticlines and the presence of long faults of the thrust type.

Other geosynclines.—The writer has had an opportunity to test his theory in only one other area of geosynclinal character. That area however, seems to offer convincing confirmation of the theory. It is an area which has been studied intensively by many geologists and is probably better known than any with the exception of the southern Appalachians. The study of the Alps was begun by Heim many years ago and was carried forward by such men as Lugeon, Argand, Haug and Collet. The latter has recently published a most excellent summary[11] in which the results of researches carried on up to 1927 are analyzed. Figure 16 is based on the work of these men, but was prepared by the writer. It shows the evolution of initial anticlines presumably along lines of weakness in the basal complex. It further shows how these have acted later as struts to produce the major anticlines of the Alps. The further complications induced by still later thrusting and overfolding have resulted in a complex that is, of course, very dissimilar to the pattern of the present Appalachians.

Summary.—Maps showing thickness and distribution of Paleozoic sediments prepared by the writer in 1931 indicated the existence of boundary faults (or fault zones) of great displacement. These faults were probably normal faults at first similar to the Catoctin faults, but later became shear zones between the geosyncline and the land mass supplying sediments. Since the southern Appalachian geosyncline lends itself best to a demonstration of the evidence, its characteristics are enumerated, for it is believed that the formation of the boundary faults also provides an explanation of the structural features now found in the Valley province and the Appalachian Plateau province. Previous authors have emphasized the evidences of lateral or tangential thrust from the southeast. They have attempted to explain the many sub-parallel folds, extending nearly 175 miles west of the Blue Ridge, as primarily due to the competence of a thick limestone sequence to transmit the thrust from the east. The writer believes that this concept needs to be modified and that the plane of effective transmission of thrust lay at all times below the lowest level

[11] L. W. Collet, *The Structure of the Alps*, Edward Arnold Company, London (1927).

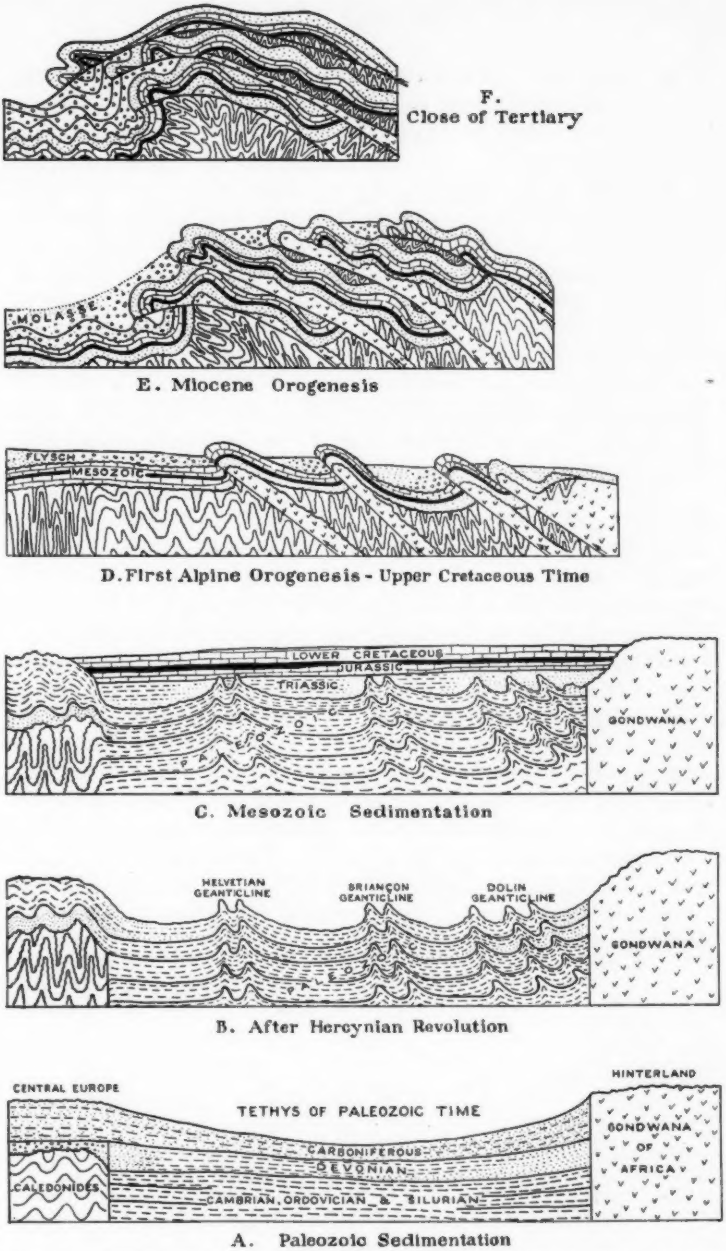


Fig. 16.—Generalized cross sections to show evolution of Alps Mountains. Notice formation of initial anticlines and their influence on later deformation.

of the sediments in the geosyncline. Furthermore, he believes that the folds and faulted folds are secondary and that the primary features which produced them are fault slices rising from the foundation stone of the geosyncline.

Granting, as many believe, that the principal cause of the thrust was the downward pressure generated by the heavy rocks under the Atlantic, then the wedge-shaped cross section of the earth's crust would translate the stress into a horizontal direction. The first effect of this horizontal stress would be to overturn the boundary faults toward the northwest or the formation of a geanticline near the eastern seaboard as illustrated by Willis' classical experiments. Further increments of stress pulsations would cause a shear plane to develop at its western margin. This would be at first a high angle thrust fault which would absorb nearly all the energy transmitted and, as a result, experience greater and greater displacement.

The landmass of Appalachia was thus created. Violent movements of orogenic character such as occurred at the time of the Taconic revolution, etc. would be registered by great displacement at its western margin, but would find only weak expression farther west in the geosyncline. Each pulsation would produce high land and coarse detritus to build deltas, etc. Eventually the wedge-shaped geanticline driven upward would bring the focus of primary force application nearer to the geosyncline. This happened in Pennsylvanian time when many sub-parallel faults in the pre-Cambrian foundation, west of the main boundary fault, felt the effects of the continued thrust from the southeast. Since the direction of easiest relief is upward these faults allowed blocks to slide upward and westward. Each block pushed up the overlying prism of sediments, in some places producing anticlines, in other places faulted anticlines or thrust faults. The second pulsation of Pennsylvanian time seems to have affected an area lying still farther west and nearly coinciding with the present Appalachian Plateau province.

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RECENT DISCOVERIES AND PRESENT OIL SUPPLY IN CALIFORNIA[1]

HAROLD W. HOOTS[2]
Glendale, California

ABSTRACT

Demand for California crude requires the production of about 200,000 barrels annually. Discoveries during the last 4 years have added only an estimated 135,000 barrels to the reserve supply. Present producing areas, if curtailment is entirely successful, will yield oil at a rate adequate for expected demand until about 1939. It is estimated that all resources of the state, including present shut-in production, will be required to meet the demand in 1940 unless important new discoveries be made. The discovery of suspected deep zones may delay a shortage of oil until 1943–45. New fields are becoming increasingly desirable and may be expected to alleviate or further delay actual shortage.

INTRODUCTION

Discoveries of new supplies of oil in California during 1935 have been insignificant when the total of this new supply is compared with yearly demand or with estimated decrease, during this same period, in the ability of pre-existing fields to yield oil. For this reason, only brief mention is made of these minor discoveries and of the geology apparently controlling the accumulation of oil in these new areas. Since the magnitude of total annual discoveries has declined with slight interruption from more than 1 billion barrels in 1928 to about 10 million barrels in 1935, it seems more important to present an estimate of the effect of this decline upon California's supply of oil, and of more interest to speculate as to the future.

DISCOVERIES IN 1935[3]

Discoveries in California during 1935 have been extremely meager, but have included gas fields, oil fields, and deeper oil zones in one field.

[1] Read before the Association at Tulsa, March 21, 1936. Manuscript received, March 16, 1936.

[2] Geologist, Union Oil Company.

[3] Developments in the early months of 1936, accounting for 3 important new fields, suggest that the downward trend of new discoveries has been reversed. The Continental Oil Company completed its initial well in the new Javon field, Ventura County, in March, 1936, producing 570 barrels daily, 29.5° A.P.I. gravity, at a depth of 5,501 feet. The Union Oil Company obtained its first large well in the Santa Maria Valley field in April with an initial daily flow of 2,380 barrels, 16.4° A.P.I. gravity, at a depth of 2,576 feet. The Shell Oil Company discovered the Old River field, Kern County, on June 2, with its Stephens No. 1 well producing 800 barrels daily, 61.3° gravity, and 13 million cubic feet of gas at a depth of 7,888 feet.

GAS FIELDS

SEMITROPIC

Location.—Thirty miles northwest of Bakersfield in T. 27 S., R. 23 E., Kern County.

Discovery.—Made by the Standard Oil Company of California in March, 1935, upon completion of Hill No. 1 with initial daily flow of about 30 million cubic feet of dry gas. Total depth, 3,200 feet; depth to top of producing zone, 3,135 feet.

Development.—Field completely developed with 38 wells drilled, 22 of which proved productive, reaching a total daily supply of about 400 million cubic feet.

Geology.—Gas is obtained from two sandy zones in the upper part of the San Joaquin clay. The geologic structure is that of a northwestward trending anticline 9 miles long and with about 100 feet of closure in the producing zone.

Geological prospecting.—The presence of folding is indicated at the surface by a prominent but low northwestward plunging ridge. Recent investigations of the geology of this area were aided by earlier deep wells and core holes, and the drilling of the discovery well was preceded by a reflection seismograph survey.

TRACY

Location.—One mile west of Tracy, 20 miles southwest of Stockton in Sec. 15, T. 2 S., R. 5 E.

Discovery.—Made by the Amerada Petroleum Corporation in August, 1935, upon completion of F.D.L. No. 2 with initial production of 35 million cubic feet of gas. Total depth, 4,063 feet; depth of producing zone, 3,973–4,063 feet.

Development.—Amerada completed a second well, Tracy No. 31–22, with an initial production of 33,800,000 cubic feet from the same zone; drilled F.D.L. No. 1 to 9,690 feet, and has been plugging and testing it by stages.

Geology and geological prospecting.—Quaternary alluvium conceals the geologic structure of this area, although there is slight physiographic evidence of broad anticlinal folding. The reflection seismograph was used successfully in mapping the underground structure and deserves the credit for this discovery. The present producing area appears to be on the southeast end of the anticline. Gas is produced from sandstone beds in the Chico formation (Cretaceous).

OIL FIELDS

It is estimated that new oil fields and deeper zones discovered in California during 1935 have added 10,400,000 barrels of oil to the state's supply—an amount equivalent to less than 20 days' demand on California's production.

TEJON RANCH

Location.—Sec. 2, T. 10 N., R. 19 W., 8 miles southeast of the Wheeler Ridge field.

Discovery.—Made by the Reserve Oil and Gas Company on completion of its Tejon No. 1 in June, 1935, with initial daily production of 45 barrels clean oil, 16° A.P.I. gravity, pumping. Total depth, 2,694 feet; depth of producing zone, 2,665–2,694 feet.

Development.—Two core holes and two additional wells for production have been drilled. No. 4 was abandoned as dry and No. 5 is expected to be placed on production in March, 1936.

Geology.—Structure is concealed beneath Quaternary alluvial fan deposits. Accumulation of oil is believed to be due largely to lensing out updip of a Middle Miocene sandy zone, and in minor degree to the presence of a structural terrace.

Geological methods.—Interpretation of exposed geological features and of information from core holes led to this discovery. Surveys by electrical conductivity, magnetometer, and reflection seismograph were subsequently used to determine underground structure.

BARTOLO (EAST MONTEBELLO)

Location.—Two miles north of Whittier and 1 mile southeast of the Montebello field.

Discovery.—Made by Woodward Oil Company with completion of its Lapworth No. 1, in September, 1935, with initial daily production of 125 barrels of oil, 28° A.P.I.

gravity (dry), cutting 20 per cent water; pumping. Total depth, 3,224 feet; depth of producing zone, 3,090–3,167 feet.

Development.—Four additional wells have been drilled in this area as a result of this small discovery, three of which were failures, but one was completed with 40 barrels net oil a day, cutting 50 per cent water.

Geology.—Production is obtained from a sandy zone just below the Pliocene-Miocene contact. Structure is chiefly monoclinal, with accumulation due to unconformable overlap, lenticularity, or one or more faults. Discovery of this apparently small isolated area resulted from an attempt to extend eastward the recently developed area of Miocene production of the Montebello field.

EL SEGUNDO

Location.—Section 18, T. 3 S., R. 14 W., just east of El Segundo and 3 miles southeast of Playa del Rey.

Discovery.—Made by the Republic Petroleum Company on the completion of its El Segundo No. 1, in September, 1935, with initial daily production of 250 barrels net oil, 28° A.P.I. gravity, 10 per cent water. Total depth, 7,405 feet; depth of producing zone, 7,320–7,382 feet.

Development.—No other producing wells. One well drilling.

Geology.—Production is obtained from the basal conglomeratic sandstone of the Modelo (Upper Miocene) formation, which constitutes the lower oil zone of the Playa del Rey field and which rests directly on Franciscan (Jurassic ?) schist in much of this coastal area. Quaternary aeolian and marine deposits at the surface conceal what is considered to be anticlinal structure. Lenticularity of the producing zone may be an important cause of this local accumulation.

Geological methods.—Interpretation of the records of abandoned wildcat wells is reported to have led to the drilling of the discovery well.

DEEPER OIL ZONES

Deeper drilling in the search for oil zones in proved fields has been one of the most important phases of exploration in California during 1935. Activity of this sort has been conducted at Kettleman North Dome, North Belridge, Mountain View, Edison, Elwood, Bardsdale, Shiells Canyon, and Dominguez. Many of these deep tests were still in progress at the end of the year, with varying amounts of encouragement.

Although deeper drilling at Dominguez increased the thickness of the productive Miocene zone originally discovered in 1934, Shiells Canyon in Ventura County is the only California field in which a deeper zone was discovered and proved productive in 1935.

Shiells Canyon.—The Oak Ridge anticline or anticlinal zone parallels and lies just south of the broad alluvial bed of the Santa Clara River and extends from the South Mountain field, just south of Santa Paula, 14 miles eastward to the Torrey Canyon field south of Piru. Lying between the South Mountain and Torrey Canyon fields and along this same anticlinal zone are the Bardsdale and Shiells Canyon fields. All of these fields have the continental Sespe (Oligocene+) formation exposed at the surface, and all of them produce from sandstone beds in the middle half of this same formation. All fields are similarly asymmetrical with their north limbs much the steeper and locally overturned against a southward dipping thrust fault which passes beneath the fields.

The Texas Company, in July, 1934, located its Shiells No. 128 on the south limb of the Shiells Canyon fold, in the southern edge of the producing area. Credit for the later success of this well must go to careful geological field work and accurate interpretation of the effect, at depth, of surface structure on the position of possibly deeper oil zones.

The Texas Company's Shiells No. 128 was drilled to a total depth of 7,423 feet. Several zones were tested in the Sespe below known producing sands. Also, possible zones in the underlying marine Eocene were penetrated and tested. Tests of the Eocene were unsuccessful and the well was plugged to 4,088 feet and completed on the pump, October 12, 1935, with initial daily production of 300 barrels net oil, 36.1° A.P.I. gravity (clean), cutting 30 per cent water, from three separate zones in the Sespe between 3,715 and 3,878 feet. In November, 1935, another well, drilled by the Bankline Oil Company, $\frac{1}{4}$ mile east, was completed from a slightly higher zone with initial flow of 720 barrels (gross), 37° A.P.I. gravity (clean), 11 per cent cut. Within a few days this well was placed on the pump and was producing about 120 barrels daily. The Bankline Oil Company's Calumet No. 2 was completed in February, 1936, with 600 barrels of clean oil, but within 2 weeks had declined to 260 barrels daily.

CALIFORNIA'S KNOWN SUPPLY OF OIL

A committee of the American Petroleum Institute composed of past-presidents of The American Association of Petroleum Geologists recently prepared estimates of oil reserves for the United States and for each major producing state.[4] California was estimated by this committee to have a known reserve of 3 billion, 500 million barrels of oil recoverable by ordinary current methods of production under prices prevalent on January 1, 1935. This amount represents 28.74 per cent of the total estimated reserves for the United States and, offhand, might be considered sufficient for a number of years. The most important feature of the oil-reserve situation in California, however, is not the size of the total known reserves, but rather the length of time during which these reserves will yield an adequate daily supply.

The average California oil field as compared with other producing fields of the United States is characterized by long life, moderate decline during the initial period of flush production, and many years of slowly declining and settled production while on the pump. At present about 60 per cent of the state's total production comes from

[4] "Petroleum Production and Supply," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 1 (January, 1936), pp. 1–14.

pumping wells, while 85 per cent of the remainder, although flowing, is coming from fields or zones discovered 4–10 years ago and now declining. Discoveries made in the last 4 years are of minor importance as to both present daily yield and maximum daily potential if fully developed. The period of flush production is past for all fields except Kettleman North Dome (1928),[5] Kettleman Middle Dome (1931), North Belridge deep zones (1930 and 1931), Mount Poso (1926), Round Mountain (1927), parts of Mountain View (1933), Ventura Avenue deep zones (1925–1931), Inglewood deep zones (1925 and 1934), Dominguez (1923–1934), and West Coyote deep zones (1923–1930)—and it appears that the flush production from all of these except Kettleman North Dome, North Belridge, Ventura Avenue, Inglewood, Dominguez, and West Coyote will be near an end by 1940.

The more or less regular discovery of new fields or new zones with large initial daily capacity is necessary to maintain daily supply on a level with uniform demand. Although present daily potential supply is considerably in excess of current demand, new discoveries in 1935, if completely developed, probably would not produce more than 10,000 barrels daily, and the total discoveries for the last 4 years, if similarly developed, probably would not yield 80,000 barrels daily for 1 year.

RATE OF PAST DISCOVERY

The accompanying chart (Fig. 1) shows by years the estimated magnitude of oil discoveries in California since 1915. Peaks in the rate of discovery occur in 1921, when Long Beach, Huntington Beach, and the Bell Zone of Santa Fe Springs were found, and in 1928, when Elwood, deeper zones at Santa Fe Springs, and Kettleman North Dome became established producers. The rate of discovery has been erratic, but from 1919 to 1928, inclusive, there did not elapse two consecutive years in which combined discoveries did not exceed demand. This scarcity of lean years, together with the excessive new reserves of 1919, 1920, 1921, 1928, and 1931, permitted the development of a sizable backlog for future needs. It is apparent from the chart that this reserve supply has been rapidly depleted during the last 4 years, for during this period an estimated total of only 135 million barrels of new oil has been found—an amount sufficient for 8 months' requirements if, by magic, it could be produced in that short time.

The effect of the past discovery rate on known reserves appears

[5] Year of discovery.

in Figure 2. In this chart estimated reserves are shown for the first of each year as calculated back from all present available information on past production and estimated future. The upper part of each column indicates the estimated amount of oil discovered in the immediately preceding year. It is clear that there has been a steady decline in total estimated reserves since January 1, 1932, and, except for this year, a steady decline since January 1, 1929. It is equally evident that

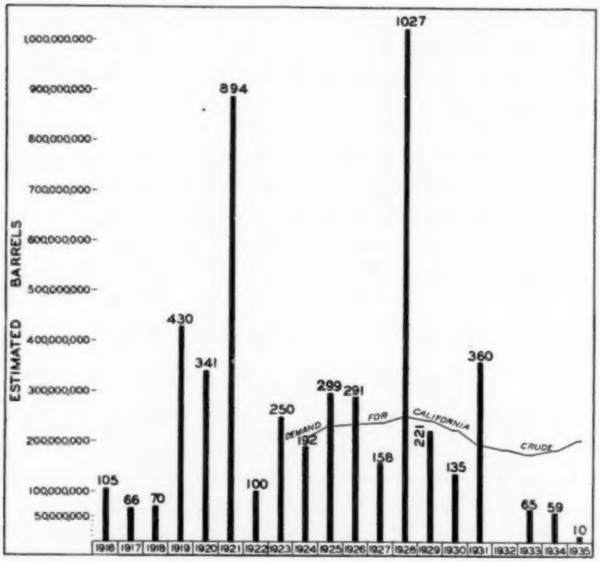

FIG. 1.—Discoveries of oil in California by years.

the major additions to estimated reserves occurred in 1921 and 1928 and that for uniform periodic recurrence of similarly large additions 1935 should have been a good year.

PRESENT AND ESTIMATED FUTURE DAILY SUPPLY FROM KNOWN RESERVES

Production of oil in California, as elsewhere in the United States, has been curtailed since 1929. The amount of present actual curtailment is debatable, but it is certain that it is much less than the official percentages used as the basis for allotting production from

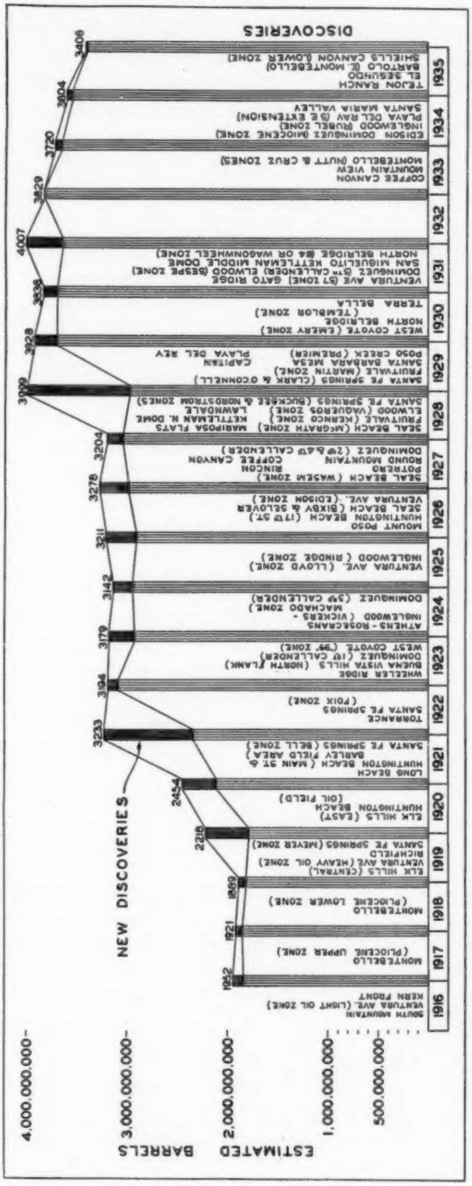

FIG. 2.—California oil reserves estimated for beginning of each year. Entire column indicates total reserves. Upper part indicates new reserves discovered in preceding year.

1930 to May, 1935. Almost immediately after invalidation of the National Recovery Act and its accompanying National Petroleum Code in May, 1935, production was increased in flush fields and curtailment was practically abandoned in all fields except those restrained by enforced gas conservation or controlled by major companies who considered the future life of these fields of more value than increased present production. The subsequent 8 months' period of less restrained production provided exceptional conditions for an investigation and a fairly accurate estimate of the potentialities of currently producing fields.

A committee composed of well informed engineers from major producing companies of the state was established in January, 1936, for the purpose of arriving at the best possible estimate of the present daily potential supply. This committee reached the conclusion that the present producing fields of California, without the repair and opening of shut-in wells, are capable of maintaining, under conditions of voluntary curtailment in line with good engineering practice, a daily output of about 670,000 barrels throughout 1936. In defense of this estimate, as opposed to much higher estimates of present potential, it can be said that this committee, with all available information on pressure conditions in many fields, gave extraordinary consideration to the necessity of closing in or restricting production from wells with high gas-oil ratios.

A further conclusion of at least some members of this committee is that production, if maintained at 670,000 barrels daily during 1936, would experience natural decline thereafter.

It is of interest to use these conclusions as a basis for speculation as to the daily supply of oil to be expected in future years from present known reserves.

Should the present curtailment effort be entirely successful, the state's output will be curtailed to about 537,000 barrels a day during the remainder of 1936—a figure agreed upon by authorities as in line with the current rate of consumption. Such curtailment would hold in reserve for most of 1937 a daily supply of about 130,000 barrels.

Without curtailment for the remainder of 1936, and without rehabilitation of producing and shut-in wells, it might be expected that California production would decline about 20 per cent during 1937—or from 670,000 to 535,000 barrels daily by the end of the year—providing an average of about 600,000 barrels daily for 1937.

With curtailment of 130,000 barrels a day during the remainder of 1936 and with continued curtailment of any excessive production

during 1937, the ability to produce an average of 600,000 barrels daily—or at least an amount equal to expected demand—should be extended to the end of 1938. To insure this it is considered that continuation of present development programs in proved areas will be necessary.

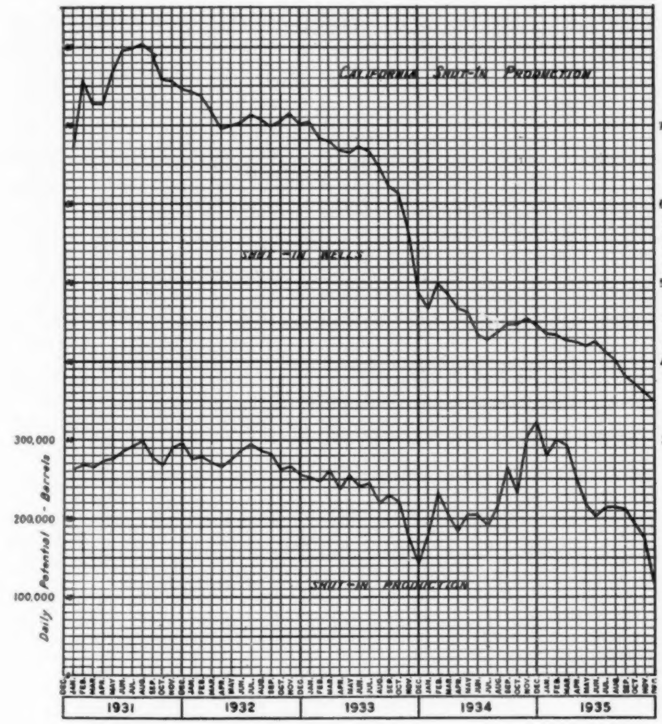

FIG. 3.—California shut-in production. Prepared from data compiled by W. R. Wardner, Jr., statistician with the State oil umpire.

Unless important additional reserves in the form of new fields or deeper zones shall be discovered, it does not appear unreasonable to expect that California must begin in about 1939 to depend in considerable degree on the rehabilitation of old wells, both producing and shut in, to provide a daily supply of crude comparable to that deemed necessary at present.

The reconditioning of old wells is in progress now and the reopening of shut-in wells as early as 1931 is apparent from examination of Figure 3, prepared from data compiled by W. R. Wardner, Jr., statistician with the State oil umpire. Currently shut-in wells are estimated to be capable of yielding 117,313 barrels daily and, when threatened shortage and crude prices justify, these and new wells in proved but undeveloped areas might be made to produce 150,000 barrels. Assuming that no important new discoveries be made, it is estimated that all oil resources of the state will be needed in about 1940 to maintain an annual supply equal to present demand. Subsequent decline, assuming that no major improvement be made in present pumping methods, might be expected to carry the state's average daily production to 500,000 barrels in 1941, 400,000 barrels in 1943, and 300,000 barrels in 1947.

REASONABLE EXPECTANCY FROM DEEPER ZONES

Several fields in California are considered to have good possibilities for the discovery of deeper zones. Although there is little basis for an estimate, it would be reasonably optimistic to assume that all of these possible deeper zones will yield a total of 500 million barrels and that they will be discovered and be produced at a rate which will delay a shortage of oil for an additional 3 or 4 years and permit California to produce its present daily demand of 550,000 until 1943–1945.

The foregoing estimate of the amount of oil to be discovered in deeper zones may not even be approximate—it may be 50 per cent too large or 100 per cent too small—but the conclusion to be drawn can be revised only as to time unless large reserves in new fields are discovered.

TRENDS IN EXPLORATION ACTIVITY

The rate of discovery of new fields (excluding deeper zones in old fields) has declined rapidly since 1928. The cause of this decline is multiple, but in major degree at least is one of economics. New fields can not be discovered without the drilling of wildcat wells, and the number of new fields discovered will have some relation to the intensity of wildcatting activity. Figure 4 shows clearly that such activity was drastically curtailed during 1931 and has been allowed to remain at a comparatively low rate; and that since 1931 the magnitude of new field discoveries similarly has been low. Renewed expansion of

wildcatting activity has been retarded by reduced profits in the industry, increased hazard of wildcat ventures, and decreased geological activity.

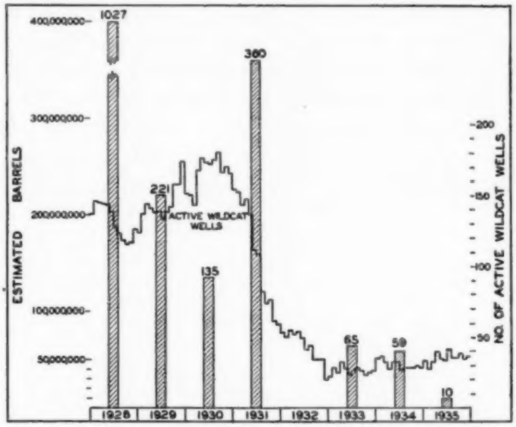

FIG. 4.—California wildcat activity and discoveries in oil. Wildcat activity by Martin Van Couvering.

The last 3 years have seen the adoption and use of various geophysical methods on a large scale in California. By use of these methods anticlinal structures have been located and mapped, but resulting exploration by drilling has been disappointing in that no oil fields and only a few gas fields have been found.[6]

Future success in the discovery of new oil fields of major proportions in this state depends upon the intensity and character of geological activity. Hidden fields unquestionably exist, but their discovery may require more thorough investigation of fundamental geological problems and a considerable realignment of geological activity. This geological activity must necessarily include intelligent use of geophysics, micropaleontology, and any additional tools that may be devised.

ACKNOWLEDGMENTS

The writer is indebted to Desaix B. Myers, chief geologist of the Union Oil Company of California, for permission to publish this

[6] The Old River field, discovered by the Shell Oil Company in Kern County, June 1, 1936, was located by this company's reflection seismograph.

paper, and to A. C. Rubel, Edmund Jussen, Jr., E. B. Noble, and W. W. Heathman for suggestions and criticisms. E. R. Erb, of the same company, provided data on demand for California crude.

G. C. Gester, chief geologist of the Standard Oil Company of California, C. M. Wagner, chief geologist of the General Petroleum Corporation, and R. M. Barnes, chief geologist of the Continental Oil Company, have provided considerable data necessary for the preparation of the charts on oil discoveries and oil reserves. J. R. Pemberton, State oil umpire, and W. R. Wardner, Jr., statistician of the umpire's office, have collaborated generously in making available information on shut-in production and pumping well production.

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PRELIMINARY REPORT ON THE FITTS POOL, PONTOTOC COUNTY, OKLAHOMA[1]

DON L. HYATT[2]
Tulsa, Oklahoma

ABSTRACT

The Fitts pool, classified as Oklahoma's latest major pool, has an estimated ultimate yield of 100 million barrels. It has opened an area for potential oil fields in southeastern Oklahoma, which had previously been considered unfavorable for the accumulation of oil.

The first structure making movement of importance occurred at the end of Wapanucka time; the area was faulted, accompanied by folding and some erosion. Progressive faulting and folding continued during lower Atoka time as the area was undergoing gradual uplift during deposition. It became a positive element in about lower middle Atoka time when it received its greatest amount of uplift. Except for minor oscillations, the area remained a positive element until Middle Pennsylvanian time.

The structure of the Fitts field is a faulted anticline, which lies within the Franks graben. Accumulation is controlled by a major east-west fault and associated cross faults, post-Wapanucka in age. The field is controlled on the west and the south by faults, on the north by dip of over 500 feet to the mile on the subsurface formations, and will probably be controlled on the east by regional dip.

INTRODUCTION

The Fitts pool lies within the Franks graben about 2½ miles north of the Arbuckle mountain front. This area was visited by many eminent professors and petroleum geologists because it offered a fertile field for the study of geological sections and structural geology. However, because of the intensive faulting and sharp folding which had occurred in the area, geologists were of the general opinion that oil was not present in commercial quantities. The structural conditions are far different from those in other Oklahoma oil fields. Early tests in the graben area, all of which were unproductive, confirmed this opinion.

The first commercial well in the area was W. A. Delaney's Harden No. 1, in the NE. cor. of the SW. ¼ of Sec. 30, T. 2 N., R. 7 E., which was completed in the Atoka sandstone from 1,165 to 1,185 feet, producing 30 million cubic feet of gas. Even this well did not arouse much interest, as the presence of gas was generally attributed to a sand-lens condition.

[1] Read before the Association at Tulsa, March 20, 1936. Manuscript received, April 2, 1936.

[2] Carter Oil Company.

In July, 1933, the Wirick No. 1 of E. H. Moore and associates was completed in the SE., SE., SW. of Sec. 29, T. 2 N., R. 7 E., in the Hunton formation, producing about 20 million cubic feet of gas and 30 barrels of oil a day. This was the first oil well in the Fitts pool. The well had been drilled on the theory that production might be expected from the Cromwell sandstone due to convergence into the west end of the graben, and was deepened to the base of the Hunton when the Cromwell proved to be dry. The completion of this well added hope to the possibility of Ordovician production.

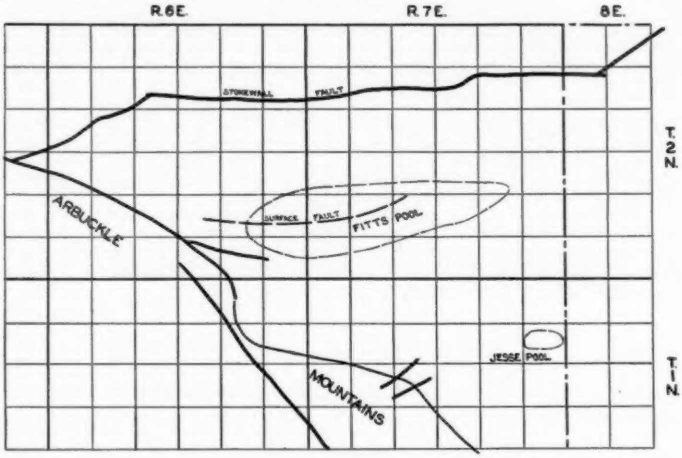

FIG. 1.—Position of Fitts and Jesse pools in Franks graben.

Ordovician production was discovered by W. A. Delaney's Craddock No. 2 in the NE. cor. of Sec. 25, T. 2 N., R. 6 E., in June, 1934, which came in with more than 300 barrels a day in the upper Bromide sand. An Ordovician structure of some magnitude and a large oil reserve were definitely proved when Shaffer's Harden No. 1-A, in the NE., NW., SW. of Sec. 30, T. 2 N., R. 7 E., completed on July 31, 1934, flowed 185 barrels an hour from the Viola limestone and the first and second Bromide sands.

McLish production was considered a possibility during the early development of the field. Production from the upper McLish sands and the basal McLish sand was discovered by E. H. Moore. In April, 1935, his Mitchell No. 1, in the NW., SW., NW. of Sec. 31, T. 2 N., R. 7 E., flowed 462 barrels the first hour after being drilled through the fourth McLish sand. This was an increase of approximately 400 barrels an hour over the Bromide production.

On July 31, 1935, his Atkins No. 3, in the SW., NW., NW. of Sec. 32, T. 2 N., R. 7 E., flowed 809 barrels in the first hour through hydril from the fifth or basal McLish sand. This was an increase of about 500 barrels an hour over the production encountered above this horizon.

The courage and persistence of independent operators in thoroughly exploring the area were responsible for the discovery of the pool. Outstanding among those deserving of credit is John Fitts, geologist of Ada, Oklahoma, who had maintained confidence in the possibilities of oil accumulation in the graben area for many years.

At present, the field is approximately 5 miles long, with a maximum width of 1½ miles, striking a little north of east, and is located in the southeastern part of Pontotoc County, including the southeastern part of T. 2 N., R. 6 E., and the southwestern part of T. 2 N., R. 7 E. It is controlled on the west by a cross fault; on the south by a major east-west fault; and on the north by dip of more than 500 feet per mile on the subsurface formations. The eastern boundary is not yet defined, but will be controlled by normal dip or faulting.

The importance of the pool lies not only in the discovery of such new oil reserves as are located in the pool, but also in that it opened an area for potential oil fields in southeastern Oklahoma, which had previously been considered unfavorable for the accumulation of oil.

Stratigraphy

ORDOVICIAN ROCKS

Arbuckle limestone.—The Arbuckle limestone is the oldest formation penetrated in the Fitts pool. Two wells have been drilled into the Arbuckle: Moore's Mitchell No. 2, in the NE., SW., NW. of Sec. 31, T. 2 N., R. 7 E., which was drilled 163 feet into the Arbuckle; and his Benton No. 3, in the NW., SW., NW. of Sec. 32, T. 2 N., R. 7 E., which was drilled 267 feet into the Arbuckle formation.

The Arbuckle was originally described as a limestone, with a maximum thickness of about 8,000 feet;[3] later, it was found to be essentially a dolomite. Thin beds of coarse sandstone and green shale have been noted in the cuttings from the wells which have been drilled into the formation.

The Arbuckle in the Fitts pool is structurally too low to produce oil.

Simpson group.—The Simpson group, made up of Bromide, McLish, and Oil Creek members, as found in the Fitts pool is corre-

[3] C. E. Decker and C. A. Merritt, "Physical Characteristics of the Arbuckle Limestone," *Oklahoma Geol. Survey Circ. 15* (1928).

lated remarkably well with the Norris Ranch surface section in Sec. 2, T. 1 N., R. 6 E., as described by C. E. Decker.[4] Differences in the

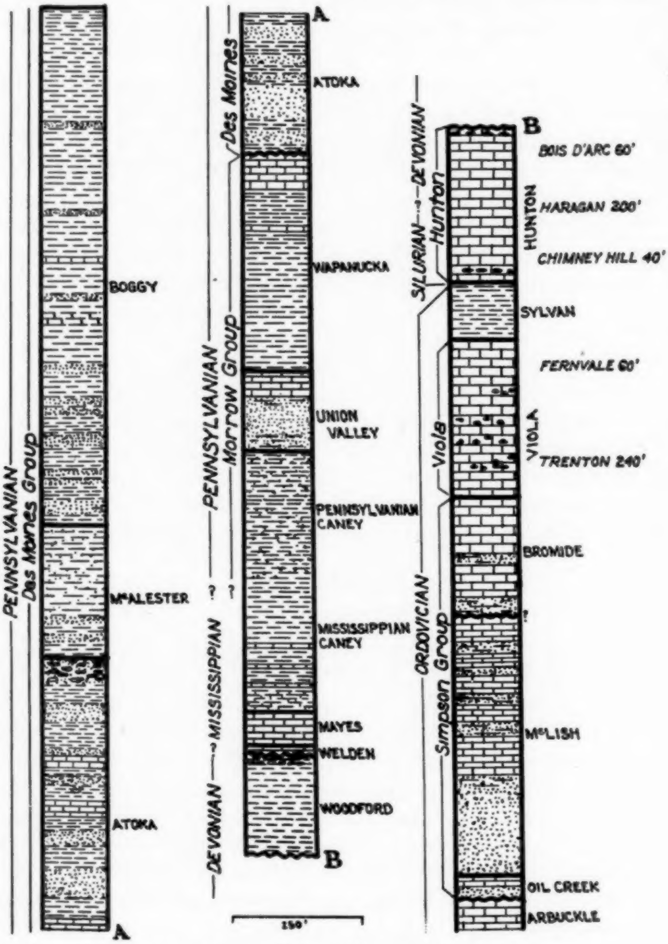

FIG. 2.—Type geologic section across Fitts pool.

intervals and minor differences in the details of lithology are noted, but in general, the two sections are readily comparable.

[4] C. E. Decker, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55*.

Oil Creek formation.—The Oil Creek formation apparently lies unconformably on the Arbuckle limestone. It was probably penetrated in Moore's Mitchell No. 2, NE., SW., NW. of Sec. 31, T. 2 N., R. 7 E., which apparently was drilled through a normal Simpson section and into the Arbuckle.

The Oil Creek formation on the mountain front in this area has a normal thickness of about 50 feet, and consists of coarse basal sandstone with a normal thickness of about 30 feet, and a limestone member about 20 feet thick marking the top of the formation. The limestone member is locally observed to be conglomeratic.

McLish formation.—The McLish lies on the Oil Creek formation and is estimated to be 605 feet thick in the field. This estimate is based on an interval of 655 feet which was encountered from the top of the McLish to the Arbuckle in Moore's Mitchell No. 2 in the NE., SW., NW. of Sec. 31, T. 2 N., R. 7 E., the bottom 50 feet assumed to be Oil Creek.

A massive sandstone body estimated to be 200 feet thick occurs at the base of the McLish, locally called the fifth McLish sand. It is coarse sand at the base and grades into a medium to fine dolomitic sand at the top. Thin-bedded fine crystalline dolomite, dense limestone, and green shale occur erratically throughout this zone. This sand is an excellent reservoir for oil accumulation, and production may be expected from it in the higher parts of this anticline.

Massive light gray dense limestone with some thin-bedded fine crystalline dolomite occurs above the basal sandstone. This is called the Birdseye limestone. It has an average thickness of 75 feet and is a very good marker in the McLish formation. Small imbedded calcite crystals occur throughout the limestone, giving it a birdseye appearance.

The 250 feet of McLish which lies above the Birdseye limestone is a mixed zone of dense limestone, sandy dolomite, and green shale. Four sandy zones occur in this horizon: they are approximately 40, 90, 140, and 200 feet below the top of the McLish, and are locally called the first, second, third, and fourth sandy zones. These sandy zones have a fair degree of consistency throughout the field, although they are lenticular and gradational in character.

The fourth McLish sand zone is the most consistent of the upper McLish sands, being well developed in all of the wells which have penetrated this horizon. This sand is the most prolific producing zone in the upper McLish.

The second and third sandy zones are the most lenticular horizons in the McLish formation, lensing in and out from well to well, in

places occurring together as one sandy or sandy dolomite zone. Good production is encountered in this horizon where sand zones are well developed.

The first sandy zone is poorly developed on top of the structure, in some places lensing entirely out, or represented by thin-bedded sandy dolomite. It is well developed on the flanks of the structure, having a normal thickness of 30 feet. Good production is found in this zone under these conditions.

Massive, grayish white, dense limestone is characteristic of the top of the McLish formation.

Bromide formation.—The Bromide formation apparently lies conformably on the McLish; however, as the Tulip Creek formation lies between the two formations in other areas, an unconformity perhaps exists.[5] The Bromide has an average thickness of 225 feet. At the base is a sand locally called the second Bromide sand, occurring approximately 170 feet from the top of the formation. It normally consists of about 25 feet of coarse sandstone, usually calcareous, underlain by a mixed zone of sandy limestone, gray crystalline limestone, dense limestone, and green shale. The second Bromide sandstone is overlain by gray crystalline limestone, dense limestone, dolomitic limestone, and green shale lentils. The most prolific Bromide production is from this sandstone.

An intraformational sandstone occurs about 110 feet from the top of the Bromide and is locally called the first Bromide sandstone. This sandstone averages about 15 feet in thickness and is about 80 per cent sand.

Production is obtained from the first Bromide sandstone where well developed. Production is also obtained from the Bromide limestones where a porous or fractured condition is encountered.

Bluish gray dense limestone with a thickness of 5–30 feet is characteristic of the top of the Bromide.

Viola limestone.—The Viola is massive limestone with an average thickness of 300 feet. It is composed of two members: the lower or Trenton Viola, with an average thickness of 240 feet; and the upper or Fernvale Viola, averaging about 60 feet in thickness.[6]

The Trenton Viola is composed of brown and gray, fine-to-medium, and coarse crystalline limestone, locally cherty. Grayish white crystalline or brown dense limestone is characteristic of the

[5] *Ibid.*

[6] C. E. Decker, "Viola Limestone, Primarily of the Arbuckle and Wichita Mountain Regions of Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1405–35.

base of the Trenton. Most of the Viola oil is encountered in the Trenton, saturation occurring erratically throughout the member.

The Fernvale Viola is white, soft, coarse, crystalline limestone, usually shaly or argillaceous at the top where it grades into the Sylvan shale, and very sandy at the base, in contact with the Trenton member. Most of the Fernvale production is encountered in the sandy phase in contact with the Trenton; however, oil saturation is occasionally noticed in the drill cuttings from the coarse crystalline limestone in the middle and upper part of the Fernvale.

Sylvan shale.—The Sylvan shale is greenish gray, finely textured shale overlying the Viola limestone. This shale is remarkably uniform in character and has an average thickness of 110 feet.

The Sylvan shale is considered as Upper Ordovician in age.

SILURO-DEVONIAN ROCKS

Hunton limestone.—The Hunton limestone is approximately 300 feet thick, and, in the pool, is divided into three members: the lower or Chimney hill member, which has normal thickness of 40 feet; the middle or Haragan member, with an average thickness of 200 feet; and the upper or Bois D'Arc member, with an average thickness of 60 feet.

The Chimneyhill member is normally composed of three lithologic units: the oölitic limestone at the base, with a thickness of 10 feet; a middle member which is a cherty glauconitic limestone, with a thickness of 15 feet; and an upper pink crinoidal limestone member, with a thickness of 15 feet.

Production is usually obtained from the oölitic member of the Chimneyhill where it is well developed.

The Haragan limestone is light gray, fine, granular, dolomitic limestone, locally somewhat marly. Interbedded greenish gray calcareous shales commonly occur in this member.

The Haragan limestone of the subsurface is equivalent to the Haragan shale and the Henryhouse shale as described on the outcrop. As study of the cuttings reveals no lithologic evidence for dividing this unit, it is locally called the Haragan limestone. It has been found that a Devonian fauna is present in the Haragan shale on the outcrop, which would place the Siluro-Devonian contact approximately in the middle of the Haragan limestone in the Fitts pool.[7]

The upper or Bois D'Arc member is grayish white, fine, medium, and coarse crystalline limestone with a thin bed of white opalescent chert at the top.

[7] Chester A. Reed, *Amer. Jour. Sci.*, Vol. XXXII (October, 1911), p. 264

A study of the well cuttings indicates that oil staining occurs erratically in the upper 20 feet of the Bois D'Arc. Oil and gas in commercial quantities may be expected from this zone where found well saturated.

Woodford formation.—The Woodford formation has an average thickness of 200 feet, and lies unconformably on the Hunton limestone.

The Woodford is essentially dark brown-to-black impure shale, containing an abundance of siderite and here and there a bed of black chert.

An abundance of *Sporangites* is characteristic of the Woodford. Conodonts are found in several horizons which have recently been identified as Devonian in age.[8]

MISSISSIPPIAN ROCKS

Mississippian Caney.—The Mississippian Caney has a normal thickness of 300 feet and lies unconformably on the Woodford formation.

Grayish white, finely crystalline limestone, 5–10 feet thick, is found in places at the base of the Mayes and has recently been determined as Welden.[9] A thin glauconitic bed is consistently found at the base of the Mayes in contact with the Welden or the Woodford formation, and is a good horizon marker.

The Mayes member overlies the Welden or Woodford, and has an average thickness of 70 feet. It is brownish-to-grayish, highly calcareous, gritty shale, which is equivalent to the Sycamore limestone of southern Oklahoma.

Dark granular calcareous shale (locally called the false Mayes) lies above the Mayes limestone. It is variable in thickness and in content of calcareous material, grading into the Mayes limestone.

The material found above this zone is essentially composed of black, brownish black, and gray, slightly calcareous shales. Interbedded siderite and dark brown dolomitic limestones are characteristic of this horizon.

The contact of the Mississippian Caney and the Pennsylvanian Caney is a matter of question and rather difficult to determine in well cuttings. The top of the Mississippian Caney is placed at the first dolomite encountered in the cuttings, which is usually underlain by platy black shale, or by the characteristic brownish black shale of the Mississippian Caney.

[8] Correspondence with E. B. Branson.

[9] Correspondence with E. B. Branson.

PENNSYLVANIAN ROCKS

MORROW GROUP

Pennsylvanian Caney.—The Pennsylvanian Caney has a normal thickness of about 200 feet and is bluish black, finely micaceous, slightly sandy and glauconitic shale. It is very similar in character to the Union Valley and Wapanucka shales, but contains no sandstone or limestone members.

The Pennsylvanian Caney apparently lies unconformably on the Mississippian Caney; on the basis of lithology, the contact appears to be gradational. Faunal evidence shows it to be Morrow in age.

Union Valley formation.[10]—The Union Valley formation normally consists of two members: a lower sandstone member 100 feet thick, and an upper limestone member 50 feet thick.

The Union Valley sandstone is a medium-to-coarse-grained sandstone, calcareous, shaly, and very lenticular in nature. It is difficult to identify the contact of the Union Valley with the underlying Pennsylvanian Caney because of the lenticular and shaly character of the sand. This formation is known in the field as the Cromwell sandstone.

A study of the well cuttings indicates that production may be expected from the Union Valley sand only where good sand conditions are present. The Union Valley sand shows a good saturation in a few scattered wells, most of which are on the east side of the field. A dark asphaltic or residue oil staining is characteristic of the Union Valley sand throughout most of the field.

The Union Valley limestone is blue shaly, sandy, and glauconitic limestone. It is rather impure limestone which grades into the Union Valley sandstone below. Here and there, a shale break, 10–15 feet thick, is present between the two members.

Wapanucka formation.—The Wapanucka formation has a normal thickness of 425 feet. The Wapanucka is largely a shale section. Thin-bedded brown crystalline oölitic limestones occur in the upper middle part of the formation, and a very persistent gray crystalline fossiliferous oölitic limestone is found at the top of the formation, which ranges from a few feet to about 70 feet in thickness.

The Wapanucka shale has a characteristic bluish cast and is finely and evenly micaceous.

DES MOINES GROUP

Atoka formation.—The Atoka formation has an average thickness of 800 feet. The Atoka was apparently deposited rapidly, the beds

[10] R. V. Hollingsworth, *Proc. Geol. Soc. America for 1933* (June, 1934), pp. 364–65.

being very lenticular in nature and somewhat conglomeratic. The formation consists of alternating beds of calcareous sandstones, gray and black shales, and marls with some inconsistent limestone members occurring in the middle and lower part of the section. Chert conglomerates are noted in some of the wells, occurring usually at the top of the formation. One or more sponge horizons occur erratically in the middle of the section as either limestone or marl.

The Atoka in the Fitts pool is generally assumed to be lower Atoka in age and equivalent to that part of the Atoka formation cropping out south of the town of Jesse in the northeast part of T. 1 N., R. 7 E., as the stratigraphic position and lithologic character of the two horizons are very similar. Morrow fauna is reported to have been found in the Atoka cropping out south of Jesse. This report, if substantiated, will probably place the Atoka of the Fitts pool in the upper part of the Morrow group. The Atoka formation lies unconformably on the Wapanucka formation.

An enormous amount of gas is present in the Atoka sandstones, occurring usually at the 1,200-foot and 1,800-foot horizons. At present, there are thirteen gas wells producing from the Atoka sands. The wells producing from the 1,200-foot zone will average 5–10 million cubic feet a day, and the wells producing from the 1,800-foot zone will average approximately 50 million cubic feet a day.

Study of the cuttings indicates that oil in commerical quantities may be expected from the Atoka sands in local areas, particularly from the 1,800-foot zone. At present, one well is producing from the 1,800-foot zone—Crosbie's Harden No. 1-D, SW., SW., NE. of Sec. 30, T. 2 N., R. 7 E., which has an average flow of 30 barrels of oil a day.

The oil and gas reserves of the Atoka sands will, no doubt, be materially affected by contamination with rotary mud and water.

Hartshorne sandstone.—The Hartshorne sandstone is not recognized in the Fitts pool.

McAlester formation.—The McAlester formation is approximately 250 feet thick and lies unconformably on the Atoka. The McAlester shale consists of gray and dark micaceous sandy shales with interbedded lenticular sandstones and here and there a thin-bedded lenticular limestone. As a result of overlap, only the upper McAlester is present.

Gas in commercial quantities is found here and there in the McAlester.

Savanna sandstone.—The Savanna sandstone is not recognized in the Fitts pool.

Boggy formation.—The Boggy formation is present in the entire area of the Fitts pool. It has an average thickness of 1,000 feet and lies unconformably on the McAlester formation.

The Boggy consists predominantly of gray shales, green and brown clay shales, with interbedded calcareous sandstones. Lenticular sandy limestones are found in the Boggy.

Only the upper part of the Boggy is present in this area, due to overlap.

MIDDLE PENNSYLVANIAN ROCKS

Formations of Middle Pennsylvanian age crop out west and north of the field, covering most of the central and western half of T. 2 N., R. 6 E.

Structural and Geological History

The general structure of the Franks graben is a tilted block dipping northeast in the pre-Atoka formations; the surface beds dip north and northwest.

The Franks graben is triangular in shape, converging toward the west; it is bounded on the north by the Stonewall fault and on the south by the Franks fault, diverging toward the east. Faulting is characteristic of the area, the faults striking generally east and west diverging northeast as they swing out into the basin. These faults are interrupted by numerous smaller cross faults striking northeast. The cross faults do not have much vertical displacement, but where the beds can be recognized, they are found to have considerable horizontal displacement.

The general fault pattern of the graben is reflected in the subsurface structure of the Fitts pool; notice the contour maps on the Atoka and Wapanucka formations (Figs. 3 and 4), showing a well defined east-west fault with drag synclines closing into it. These synclinal areas are reflected in the pre-Pennsylvanian formations by faulting (Figs. 5 and 6), showing cross faults cutting the Viola and McLish formations, paralleling the drag synclines of the Atoka and Wapanucka formations. The thick Wapanucka and Caney shale sections apparently absorbed most of the movement, drag synclines being due to the squeezing and shearing of these shale sections.

The earliest structural movement which occurred in the Fitts pool was probably very slight warping during Ordovician time, setting up zones of weakness along which the later movements took place. The strong post-Hunton movement, characteristic of the Seminole uplift, and other structures of Oklahoma, is not expressed in the Fitts pool. Most of the irregularities from Ordovician to Wapanucka time

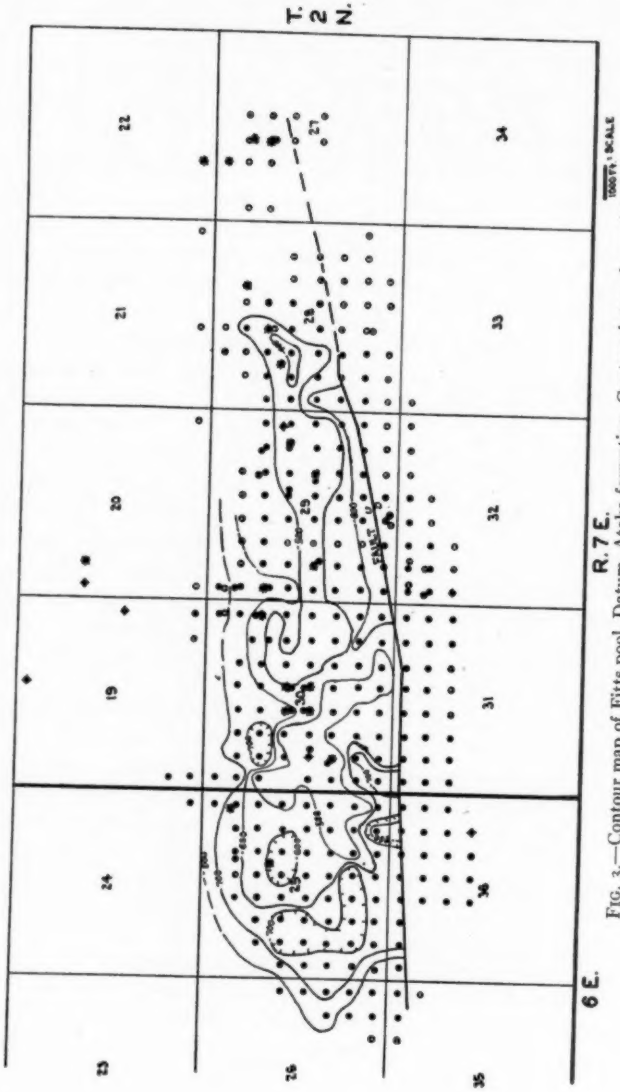

FIG. 3.—Contour map of Fitts pool. Datum, Atoka formation. Contour interval, 100 feet.

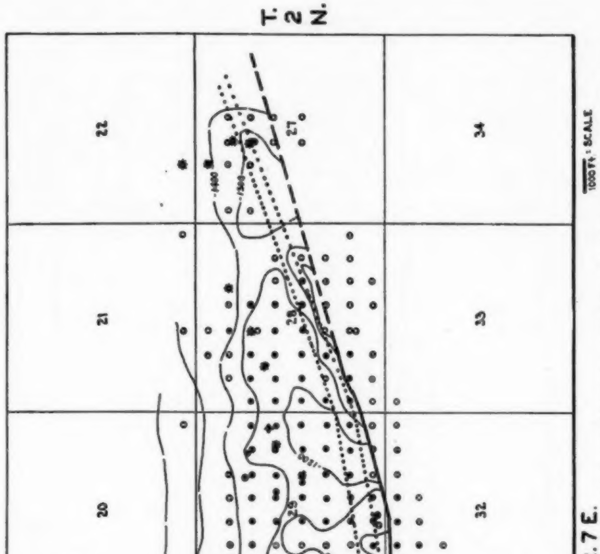

FIG. 4.—Contour map of Fitts pool. Datum, Wapanucka formation. Contour interval, 100 feet. Notice re-entrants reflecting cross faults in pre-Pennsylvanian and general relation of Wapanucka structure to Ordovician.

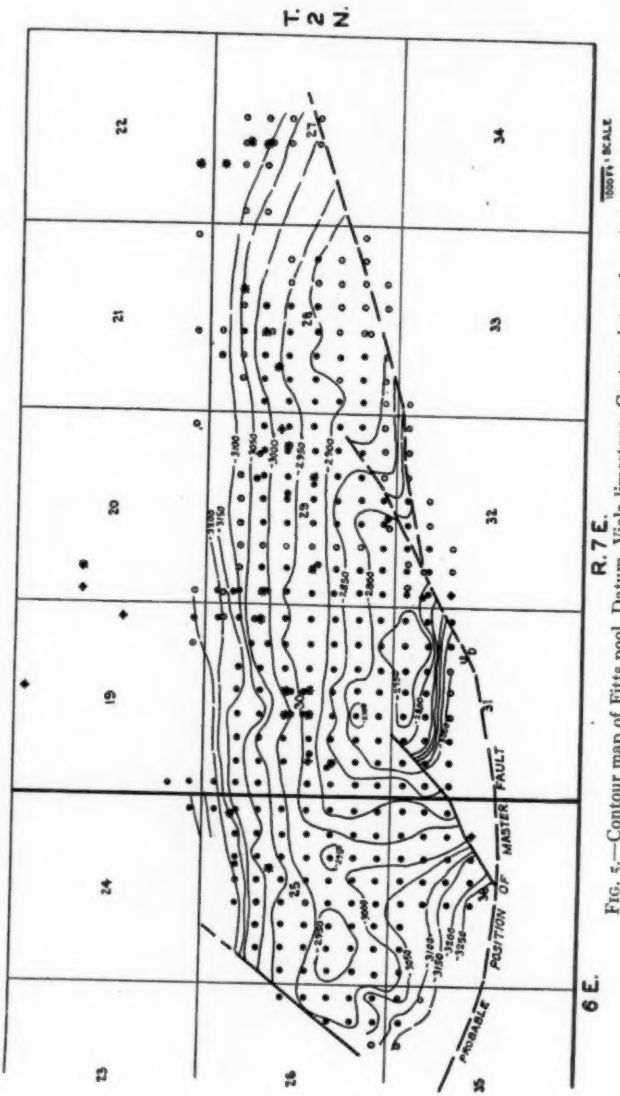

FIG. 5.—Contour map of Fitts pool. Datum, Viola limestone. Contour interval, 50 feet.

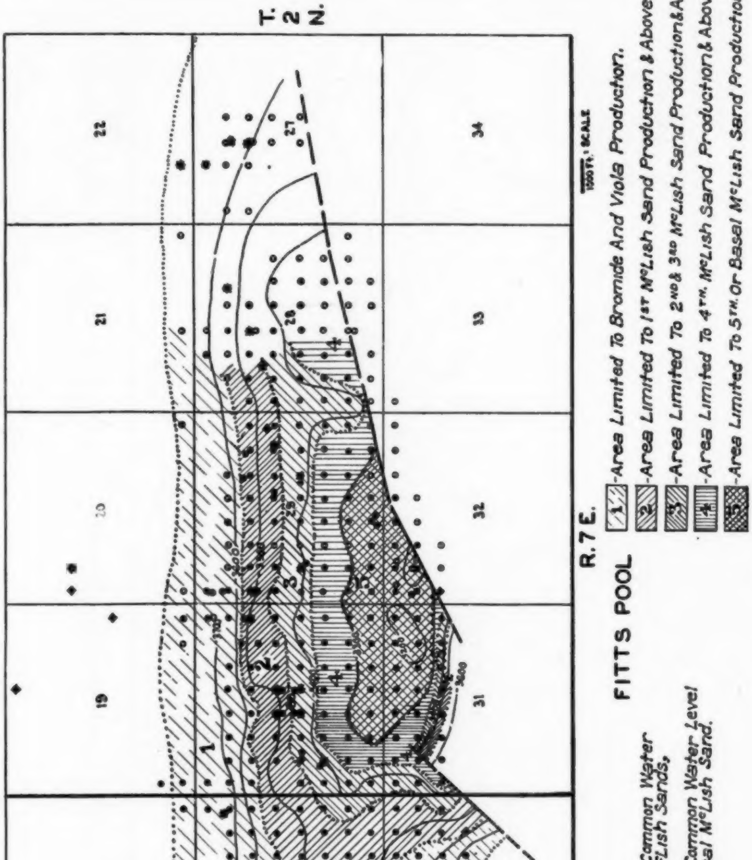

FIG. 6.—Map of Fitts pool. Datum, McLish lime.

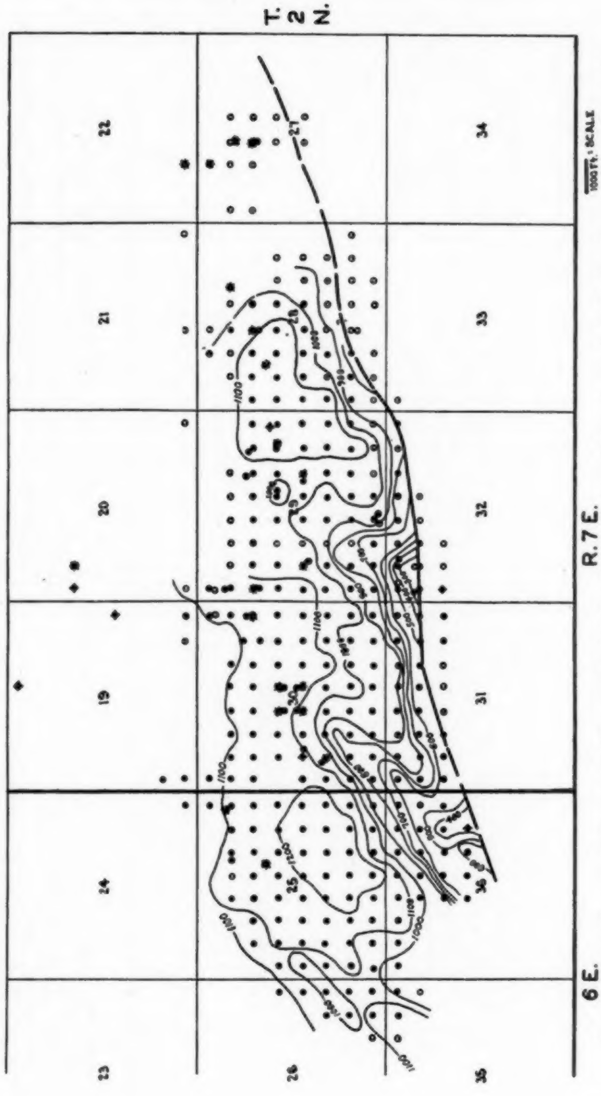

FIG. 7.—Isopach map of Fitts pool, Wapanucka to Woodford. Contour interval, 100 feet. Notice sharp irregularities only along east-west fault or cross faults, probably due to shearing.

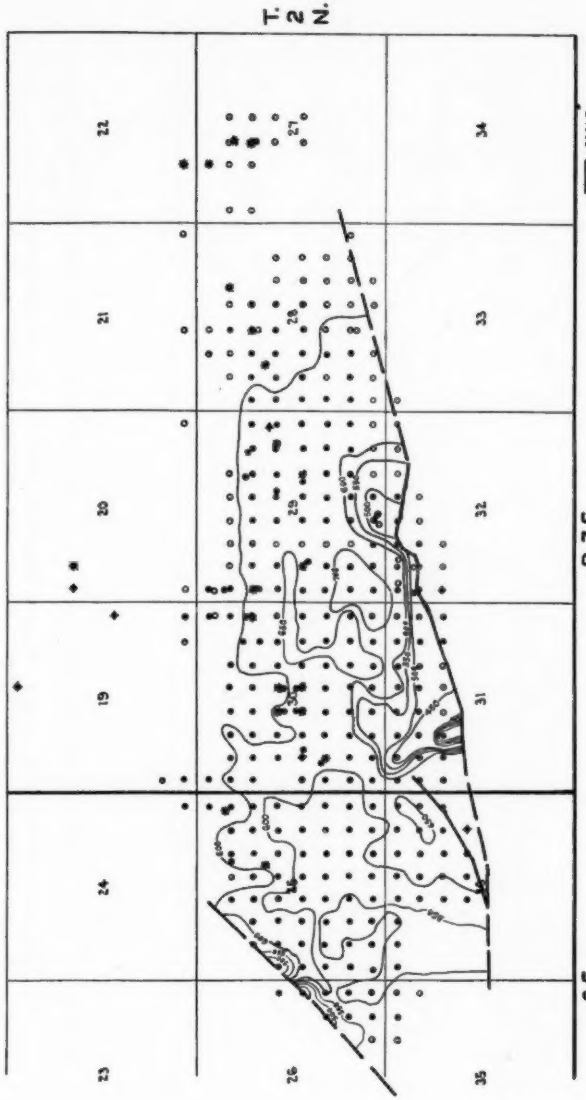

FIG. 8.—Isopach map of Fitts pool, Woodford to Viola, showing intensity of shearing associated with faults. Contour interval, 50 feet.

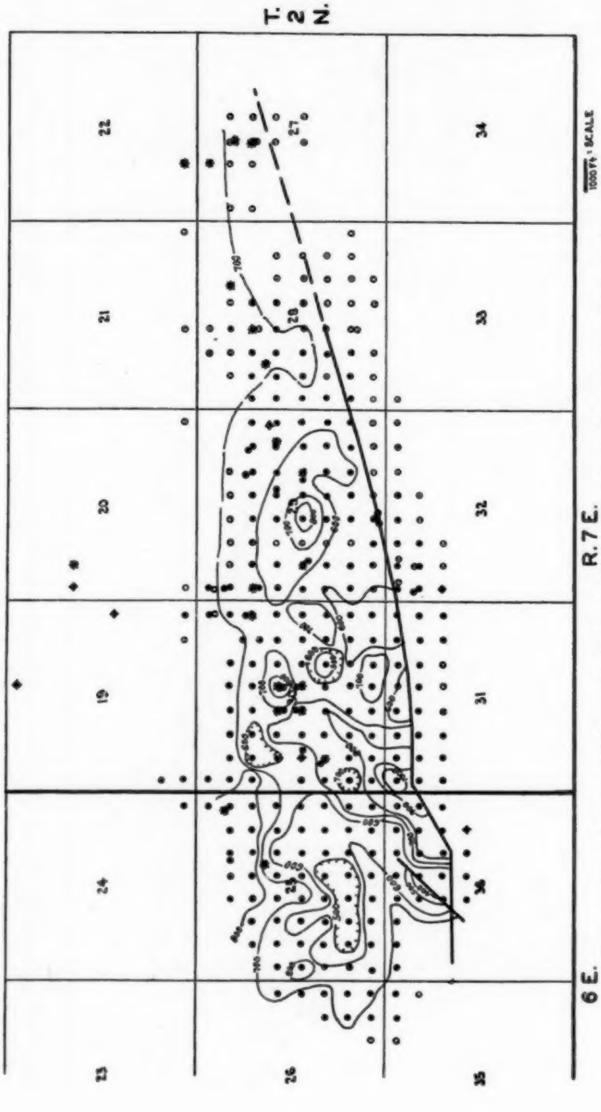

FIG. 9.—Isopach map of Fitts pool, Atoka to Wapanucka formation, showing thick Atoka section in Wapanucka synclinal areas. Contour interval, 100 feet.

are probably due to deposition. All the sharp pre-Wapanucka irregularities are along the zones of faulting or sharp folding, and are due, primarily, to shearing (Figs. 7 and 8).

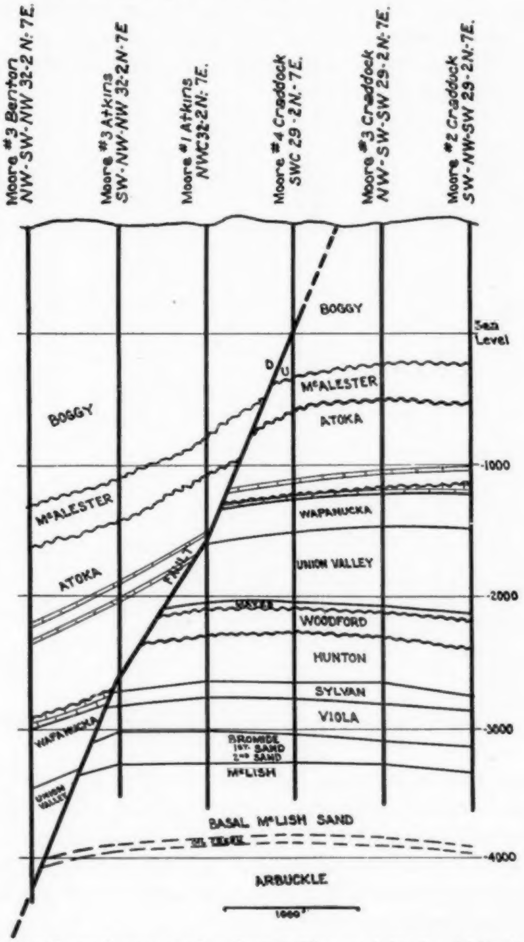

FIG. 10.—North-south cross section through Fitts pool. Notice thickening of formations on downthrown side of fault in lower and upper Atoka.

The first structural movement of importance in the graben area occurred at the end of Wapanucka time. The area was faulted, accompanied by folding and erosion, locally truncating approximately 75

feet of upper Wapanucka (Figs. 9 and 7. Notice the thick Atoka section in the Wapanucka "lows"). It is the writer's opinion that the Wapanucka formation, which can not be traced into the west end of the graben on the surface, was faulted out rather than being a result of convergence. Subsurface studies reveal that a normal section of Wapanucka is encountered throughout this region, affected locally by faulting and truncation.

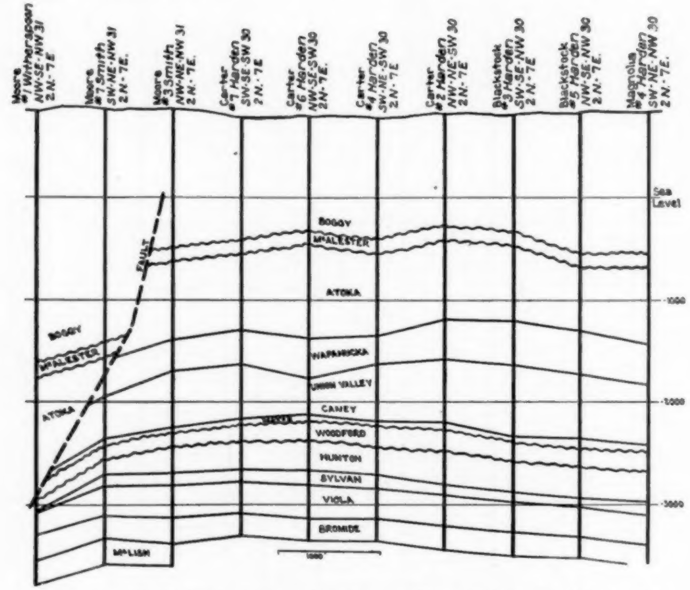

FIG. 11.—North-south cross section through Fitts pool. Notice thinning of Hunton and Sylvan due to shearing.

Following this movement, the Atoka sea advanced over the area. Subsurface studies indicate that the Atoka of the graben area is probably a shore-line phase of deposition, and is offlapped progressively toward the east by middle and upper Atoka shale. The Atoka formation can not be traced into the west end of the graben on the surface due to faulting and offlap.

Progressive faulting and folding continued through lower Atoka time, as the area was undergoing gradual uplift during deposition. Middle and upper Atoka sediments are absent due to non-deposition and some erosion. The area received its greatest amount of uplift between lower Atoka and upper McAlester time. The upper McAles-

ter overlaps the Atoka, an undetermined amount of Atoka being eroded. The graben area continued as a positive element until Middle Pennsylvanian time (Francis). The Fitts pool underwent some minor oscillations during these periods, the upper McAlester and the upper Boggy overlapping the area. Middle Pennsylvanian beds, Wewoka and Holdenville in age, overlap the Boggy.

Production in the Fitts pool is controlled by a major east-west fault and associated cross faults, post-Wapanucka in age (Fig. 10.

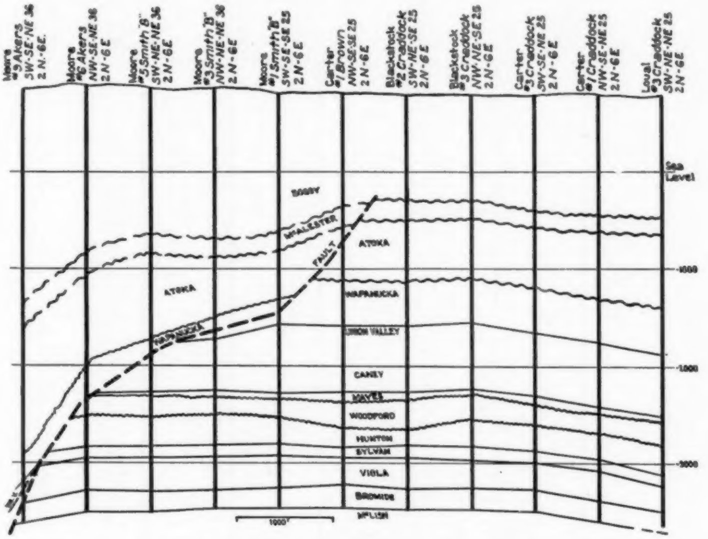

FIG. 12.—Cross section through Fitts pool, showing flattening of fault plane in shales and high angle in more competent beds.

Notice the thickening of lower Atoka and upper beds on the downthrown side of the fault). The faults are apparently the high-angle normal type; a maximum throw of 1,700 feet can be measured on the major, or east-west fault (Fig. 10). In local areas, the major fault is represented in many places by a zone of faulting, two or more faults being present, usually converging into one fault in the competent pre-Pennsylvanian formations (Fig. 13). The major fault commonly assumes a low angle in the incompetent shale horizons and a relatively high angle in the more competent beds (Fig. 12). The cross faults which appear to be shear faults probably branch off from the major fault, striking in a general northeast direction. A maximum throw

feet of upper Wapanucka (Figs. 9 and 7. Notice the thick Atoka section in the Wapanucka "lows"). It is the writer's opinion that the Wapanucka formation, which can not be traced into the west end of the graben on the surface, was faulted out rather than being a result of convergence. Subsurface studies reveal that a normal section of Wapanucka is encountered throughout this region, affected locally by faulting and truncation.

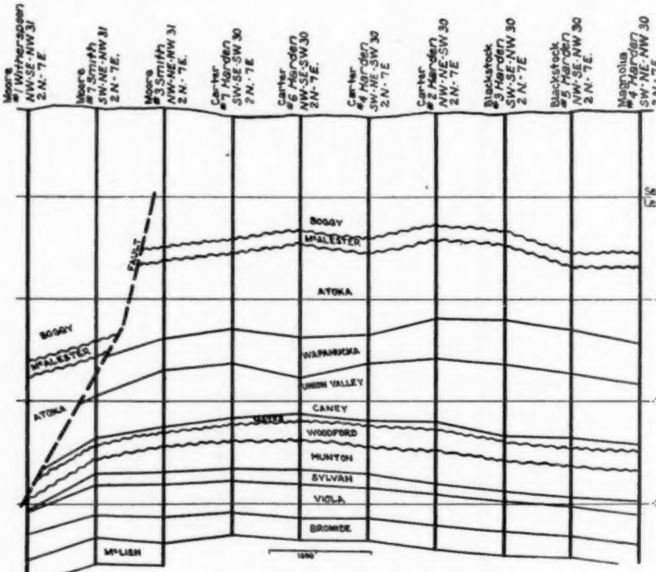

FIG. 11.—North-south cross section through Fitts pool. Notice thinning of Hunton and Sylvan due to shearing.

Following this movement, the Atoka sea advanced over the area. Subsurface studies indicate that the Atoka of the graben area is probably a shore-line phase of deposition, and is offlapped progressively toward the east by middle and upper Atoka shale. The Atoka formation can not be traced into the west end of the graben on the surface due to faulting and offlap.

Progressive faulting and folding continued through lower Atoka time, as the area was undergoing gradual uplift during deposition. Middle and upper Atoka sediments are absent due to non-deposition and some erosion. The area received its greatest amount of uplift between lower Atoka and upper McAlester time. The upper McAles-

ter overlaps the Atoka, an undetermined amount of Atoka being eroded. The graben area continued as a positive element until Middle Pennsylvanian time (Francis). The Fitts pool underwent some minor oscillations during these periods, the upper McAlester and the upper Boggy overlapping the area. Middle Pennsylvanian beds, Wewoka and Holdenville in age, overlap the Boggy.

Production in the Fitts pool is controlled by a major east-west fault and associated cross faults, post-Wapanucka in age (Fig. 10.

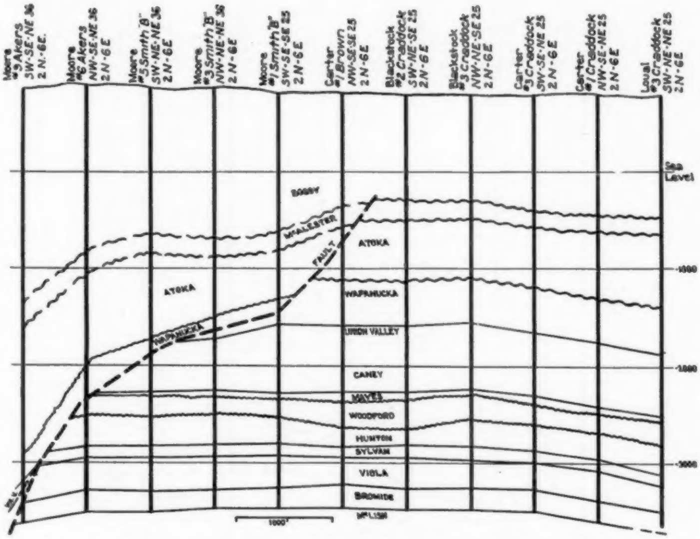

FIG. 12.—Cross section through Fitts pool, showing flattening of fault plane in shales and high angle in more competent beds.

Notice the thickening of lower Atoka and upper beds on the downthrown side of the fault). The faults are apparently the high-angle normal type; a maximum throw of 1,700 feet can be measured on the major, or east-west fault (Fig. 10). In local areas, the major fault is represented in many places by a zone of faulting, two or more faults being present, usually converging into one fault in the competent pre-Pennsylvanian formations (Fig. 13). The major fault commonly assumes a low angle in the incompetent shale horizons and a relatively high angle in the more competent beds (Fig. 12). The cross faults which appear to be shear faults probably branch off from the major fault, striking in a general northeast direction. A maximum throw

of 700 feet is noted where they branch off from this fault, the throw decreasing as the faults fade out to the northeast.

The major fault is expressed at the surface by a disturbed zone across the south half of the field. This zone is undoubtedly the result of recurrent movements along this old established zone of weakness.

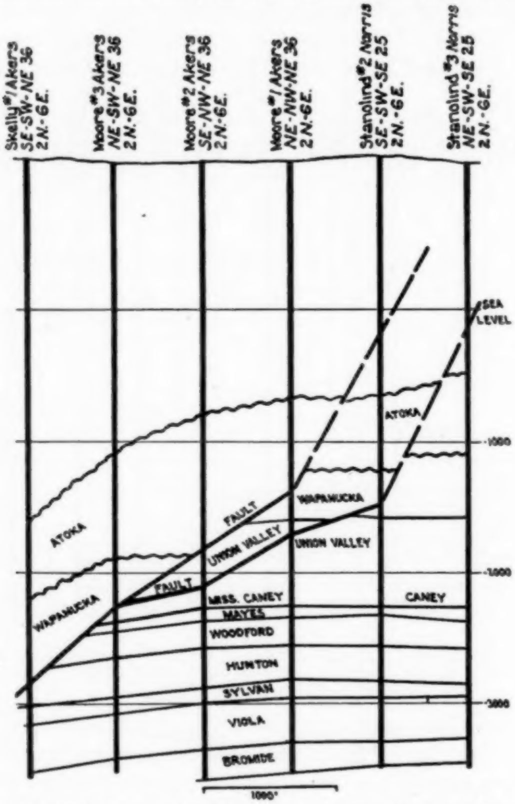

FIG. 13.—North-south cross section through Fitts pool, showing fault convergence.

Very steep south dips are noted on the south or downthrow side. The comparatively small cross faults have very little effect on the outcropping surface formations.

The movements which resulted in the structure of the Fitts pool can be summarized as follows.

1. Very slight warping or oscillation from Ordovician to Wapanucka time.

2. Faulting, folding, and some erosion at the end of Wapanucka time marking the first structure-making movement of importance.

3. Progressive faulting and folding during Lower Atoka time, as the area was undergoing gradual uplift during deposition, becoming a positive element in about lower middle Atoka time, when it received its greatest amount of uplift, and remained a positive element until Middle Pennsylvanian time, except for some minor oscillations.

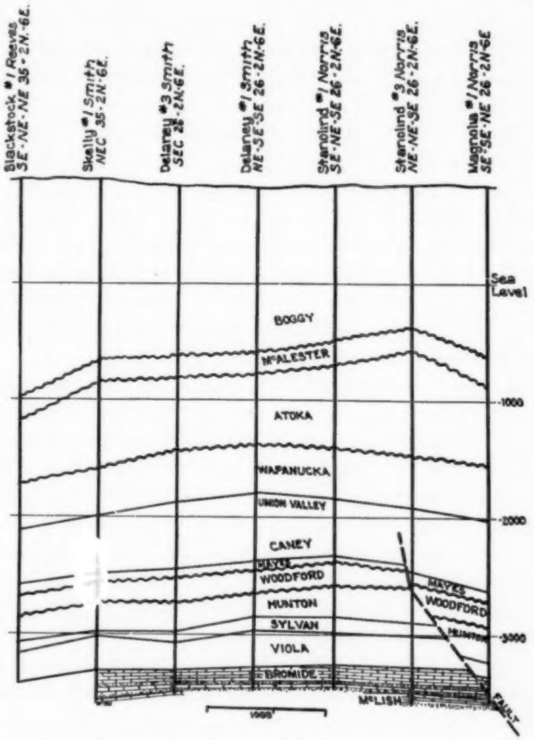

FIG. 14.—North-south section through Fitts pool, showing cross fault on west end of field.

PRODUCTION

The average bottom-hole pressure of the Ordovician producing horizons in October, 1934, was 1,900 pounds, dropping to 1,400 pounds in January, 1936, or an average decline of 30 pounds a month.

A relatively uniform water level is present on the north side of the field, at approximately 3,600 feet below sea-level, varying somewhat, due to lateral change in porosity and permeability of the limestones and sandstones. On the south side of the field, there is an erratic water condition ranging from 3,413 feet to 3,827 feet below sea-level. This variation is due to the faulting and fracturing on this part of the structure.

At present, there are 2,510 producing acres; production coming from the Atoka, Hunton, Viola, Bromide, and McLish formations.

The Atoka sands have a large gas reserve and locally will produce oil in commercial quantities. Due to their lensing condition, the areal extent is difficult to estimate.

The Hunton formation has an average thickness of 300 feet. Oil is produced from both the top and bottom with a combined thickness of about 30 feet. The wells vary in production from 25 to over 200 barrels per day.

The Viola, Bromide formation, and upper McLish sands, have a normal thickness of 775 feet, and are classified as one producing horizon. It is the general opinion that in the areas in which all of these members will produce, there should be an average yield per acre of about 60,000 barrels.

The fifth, or basal McLish sand, is classified as a separate producing horizon, having a thickness of 200 feet, with an estimated average productive thickness of 40 feet. At present, there are three wells producing from this sand, having a much higher potential than those producing from the upper horizons. It is reasonable to expect a much greater yield per acre from this sand, in the area where it is productive, than the overlying formations, because of its productive thickness and greater porosity.

The potential of the Fitts pool for January, 1936, was 588,967 barrels for 229 wells. It is the general opinion of geologists and engineers working in the pool that the probable ultimate recovery will be approximately 100 million barrels, which classifies it among the major pools of Oklahoma.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 7 (JULY, 1936), PP. 975-979, 1 FIG.

GEOLOGICAL NOTES

DEVELOPMENT AND PRODUCTION, EAST TEXAS DISTRICT[1]

This district is in the northeast corner of Texas. It is one of the most important oil and gas producing districts of the Mid-Continent area. It includes four important oil fields: Van, East Texas, Cayuga, and Long Lake. The extension of the Rodessa field into Cass County, Texas, may be proved of major size. Four major gas fields are located in this area, namely, Bethany, Waskom, Long Lake, and Cayuga.

At present, nearly all of the oil has been produced from the Woodbine sand, which is the basal member of the Upper Cretaceous. Some of the gas, in the Waskom and Bethany fields, is produced from the Lower Cretaceous.

The East Texas field still dominated the drilling and production situation throughout the United States during 1935. There were 4,036 wells completed in this field during the year, making a total of 19,519 producing wells as of January 1, 1936. More than 10,000 productive acres were added to the field, making the total productive area in excess of 128,000 acres. Most of this area was added on the east and west sides of the field. The present drilling practice on these edge wells is to set casing just above the anticipated sand, and then drill in with cable tools.

The only new field added to the district was the Camp Hill field, in Anderson County, Texas. This field was discovered by the Gulf Production Company, the first well being the Royal-Davey No. 1, completed January 31, 1935, as a gas well, making some distillate. This well was drilled to a total depth of 5,970 feet in Lower Cretaceous limestone. Several drill-stem tests were made, all of them showing salt water in the Woodbine section. The well was then plugged back to the sub-Clarksville sand, which is upper Eagle Ford in age, and completed as a gas well. While gas was used for fuel to drill another well, the gas volume dropped rapidly, and the amount of oil increased until the well began flowing oil with no free gas. Two producing sands are present in this field; the sub-Clarksville and a thin lenticular sand at the very top of the Woodbine formation. No

[1] Read before the Association at Tulsa, March 20, 1936. Manuscript received, May 6, 1936.

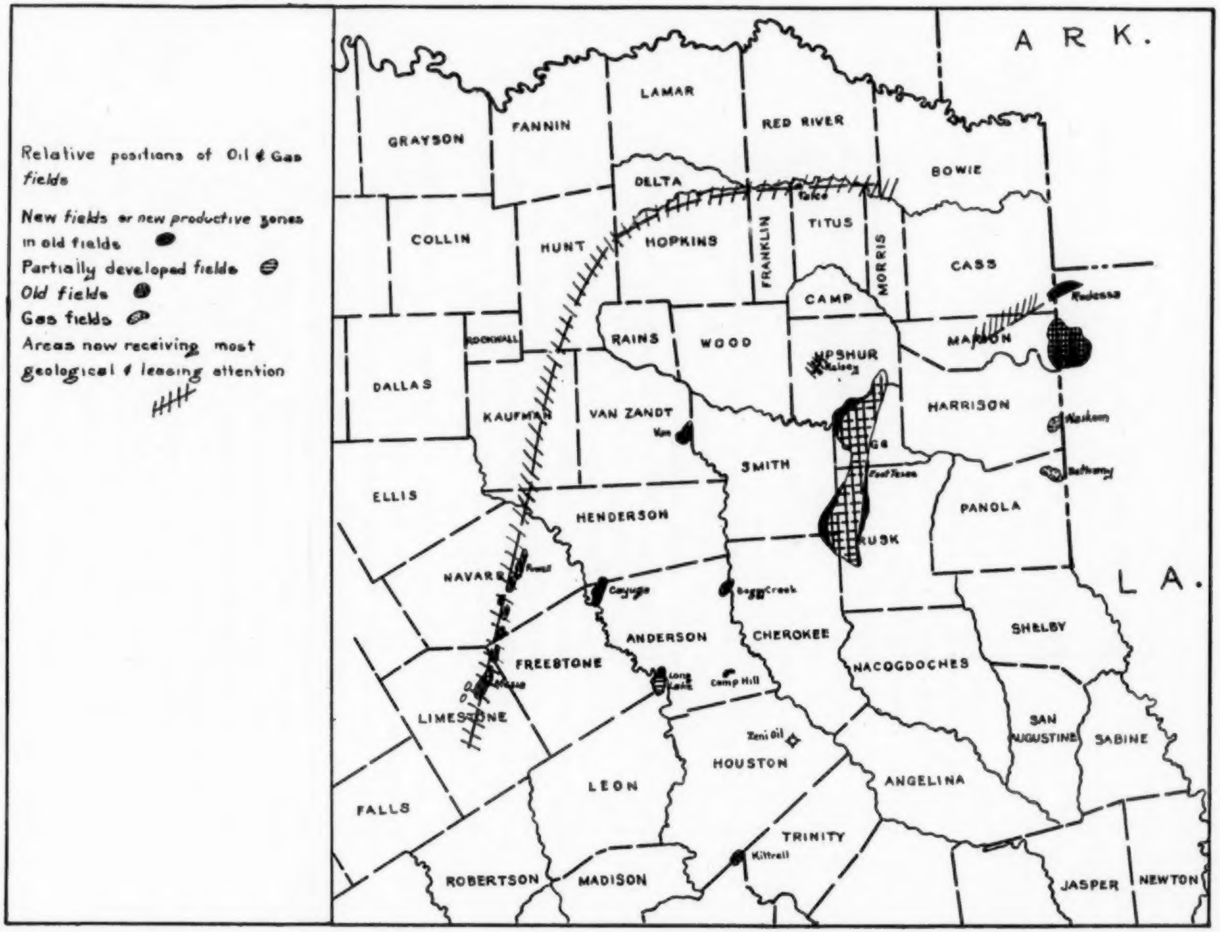

Fig. 1.—East Texas area, showing relative positions of oil and gas fields.

one well has encountered oil in both sands. These sand bodies pinch out toward the crest of the structure. The sub-Clarksville lenses out lower on the flank of the structure than the Woodbine stringer. The writer has estimated 500–700 productive acres in the known producing zones. The structure was discovered by surface geology and later checked with geophysical work.

Probably the most important discovery of the year in this district was the completion of the Tide Water-Seaboard Wills No. A-21 as a gas and distillate well, in the lower Glen Rose which is in the Lower Cretaceous. This well was drilled to a total depth of 9,085 feet, being bottomed in the Travis Peak section of the Lower Cretaceous. Seven-inch O. D. casing was run at 8,746 feet. The section below this depth was tested dry. After the hole was plugged back and the casing perforated between 8,070 and 8,110 feet, this section also was tested dry. The well was then plugged back to 7,416 feet and casing perforated between 7,210 and 7,360 feet, and the well was finally completed making 5.3 million cubic feet of gas and 130 barrels of distillate testing 55.8° gravity. Closed-in casing pressure was 3,150 pounds per square inch and tubing pressure was 3,025 pounds per square inch. It is rumored that the well is now making more fluid and less gas, with gravity rapidly dropping.

The discovery of gas and distillate in this well is of far-reaching importance, as several prominent structures have been proved dry in the Woodbine formation, but have not been tested for Lower Cretaceous production.

Another important wildcat well drilled in this district was the Housh, Thompson and Zeni Oil Company's Houston County Timber Company No. 1, in the east-central part of Houston County. This well proves the presence of porous Woodbine sand in this area, thereby increasing the possibilities of obtaining oil and gas on several large blocks in the northern part of Houston County.

Another very important well was drilled by Peveto *et al.* in the northwestern part of Titus County, near the town of Talco. This well is located in the Sulphur River fault zone, which is a continuation of the Mexia-Powell fault system. This fault system trends nearly east and west through the northern part of Titus, Franklin, and Hopkins counties, then turns in a southerly direction through southeastern Hunt County and the east half of Kaufman County. This fault zone in the counties mentioned has been tested for Woodbine production on all the well known structures, and has been proved dry. The Talco well, as the new prospect is called, made 700 feet of black oil on a drill-stem test. The oil tested 27° gravity and is from the Paluxy Lower

Cretaceous sand. The top of this sand was encountered at 4,190 feet. The total depth is 4,208 feet, still in sand. This well crossed the fault about 150 feet above the Paluxy sand. The fault has a displacement of about 600 feet. The location for the well was based on surface and core-drill work.

During the year 1935, there were 205 wildcat wells drilled, resulting in the discovery of only one small field, the Camp Hill field in Anderson County, Texas. A few good structures were condemned, for production from the Woodbine sand, by this drilling campaign.

Due to the discovery of oil and gas in the Lower Cretaceous, in the East Texas district, there will develop probably one of the most important exploratory drilling programs that this district has ever had.

WALLACE RALSTON

TYLER, TEXAS
May 4, 1936

TALCO FIELD, TITUS AND FRANKLIN COUNTIES, TEXAS

One mile east of Talco, or about 18 miles northwest of Mount Pleasant, the county seat of Titus County, Peveto *et al.* completed their C. M. Carr No. 1 on March 13, 1936, at a total depth of 4,208 feet, producing from the Paluxy formation (uppermost Trinity of the Comanche), making approximately 50 barrels of oil per day, flowing by heads through open 2½-inch tubing. On February 7, 1936, a drill-stem test with tool open 25 minutes showed 725 feet of fluid with about 600 feet of this amount being oil. The oil is black mixed-base crude, predominantly asphaltic, and has a gravity of about 24.2° Bé. On April 8, 1936, the well pumped 552 barrels on a 24-hour gauge. The test encountered the top of the Paluxy at 4,183 feet and logged the top of the pay sand at 4,190 feet.

Three other tests have been completed as flowing wells. One of these is southwest and two are southeast of the discovery well, proving the field for a length of slightly over 4 miles. One of the latter wells, Humble Oil and Refining Company's Galt No. 1, was cored to a depth of 4,349 feet without encountering water, thereby indicating a possible pay section of more than 235 feet. From this test it appears that two thick sand sections will be present in the field. The upper sand member is tentatively called the "Carr sand" since this sand was first encountered in the discovery well, and the lower sand member is called the "Galt sand." These two sand bodies are separated by a red bed and a hard, gray, bentonitic, sandy shale section. Core records of

the Galt well indicate that the well saturated section of the "Carr sand" has a thickness of 35 feet, while the "Galt sand" has a penetrated thickness of about 25 feet, having stopped in sand. In general, it appears that the average porosity is higher in the "Galt sand" horizon than in the "Carr sand." It also appears that the gravity of the oil from the "Galt sand" is slightly lower than that from the "Carr sand" section.

A pronounced fault extending across Franklin and Titus counties accounts for the structure in this area. The fault is a continuation of the Mexia-Powell fault zone. The structure was mapped as early as 1924 by various company geologists. Subsurface information shows that the displacement of the fault increases with depth.

At present there are four other wells being drilled, two derricks completed, and several locations staked.

E. A. Wendlandt

Tyler, Texas
May 12, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 7 (JULY, 1936), PP. 980-986, 1 FIG.

DISCUSSION

POSITION OF CAMBRIAN-ORDOVICIAN BOUNDARY IN SECTION OF ARBUCKLE LIMESTONE EXPOSED ON HIGHWAY 77, MURRAY COUNTY, OKLAHOMA[1]

In a recent article in this *Bulletin*, C. E. Decker[2] described a graptolite zone near the middle of the Arbuckle limestone. He identified these forms specifically with species described by Ruedemann[3] from the Upper Cambrian Lodi shale of the Upper Mississippi Valley region, and concluded that if his identifications were correct, "these graptolites have supplied some of the most significant evidence secured from the Arbuckle limestone in connecting this part of it with the Upper Cambrian...." He evidently had some doubt about this correlation, for in the same paragraph he quoted me as saying that the testimony of other invertebrates seems to place the Ordovician-Cambrian contact several hundred feet below this graptolite zone, but he evidently preferred to draw the Upper Cambrian boundary above it.

A great deal of information about the faunas in the Arbuckle limestone has been accumulating during the past few years, and although results are still far from complete, it is perhaps advisable to state just what the testimony of these other invertebrates is. This testimony is based on collections received from several sources, and I am particularly indebted to Decker for a number of them. I am also deeply indebted to officials of the Sinclair Oil Company for permission to use material and information obtained by C. L. Dake, which was turned over to me after his death.

I have not measured the section of the Arbuckle limestone as exposed on Highway 77, but have visited it on several occasions, and in making these studies I have had three measurements available for study. One of these is the section measured by Decker and published as *Circular 15* of the Oklahoma Geological Survey.[4] The others, by Dake and Ulrich, are unpublished. These last two agree fairly well and give the Arbuckle limestone (including the Honey Creek limestone and the Reagan sandstone) a total thickness of about 6,700 feet. Decker's figure is approximately 8,000 feet, exclusive of the Reagan sandstone. It has been possible to identify certain faunal zones in the upper part of these sections, and these show that the discrepancy in thickness is cumulative, and that it is largely the result of the personal equation. Good correlations have been established at a number of points from the top of the section to the base of Decker's Unit No. 184, but below this point I have been unable to make any satisfactory correlations with this section. I have

[1] Published by permission of the director of the United States Geological Survey.

[2] C. E. Decker, "Some Tentative Correlations on the Basis of Graptolites of Oklahoma and Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 301–11.

[3] Rudolf Ruedemann, "The Cambrian of the Upper Mississippi Valley. Pt. III. Graptolitoidea," *Bull. Milwaukee Pub. Mus.*, Vol. 12 (1933), pp. 307–48.

[4] C. E. Decker and C. A. Merritt, "Physical Characteristics of the Arbuckle Limestone," *Oklahoma Geol. Survey Circ. 15* (1928).

no way of knowing which thickness is the more nearly correct, but in this discussion I shall use the thicknesses from Dake's unpublished section, from which I have the greatest number of collections, and wherever possible shall give Decker's figures to the same zone in parentheses.

According to Decker's last article, the graptolites occur in a thin zone about 4,600 feet below the top of the formation. At a field conference some years ago, it was agreed that this same bed occurred near the base of Decker's Unit No. 181, the base of which was drawn 4,478 feet below the top of the formation. My other sections give this distance as 3,930 feet. I have visited the locality and collected from it on several occasions in company with Decker and others, so there is no doubt as to the identity of the bed. I have also collected from the zones both immediately above and below it and so have direct information concerning the stratigraphic relations of the collections to be discussed.

Twenty-five feet above this graptolite zone is a fossiliferous limestone from which the following forms have been obtained.

Hystricurus cf. *H. missouriensis* Ulrich
Undescribed trilobite, generically and possibly specifically identical with an undescribed form in the Gasconade of Missouri
Eremoceras sp.
Ophileta sp.
Sinuopea sp.
Pelagiella cf. *P. paucivolvata* (Calvin)
Finkelnburgia sp.

A second lot of fossils collected 10 feet below the graptolite bed contains nearly all of the foregoing forms and in addition, *Albertoceras* sp.[5]

A third lot taken about 240 feet below the graptolites contains the following.

Symphysurina? sp.
Albertoceras sp.
Finkelnburgia sp.

This collection is believed to be from the fossil bed in Unit 182. The figure 530 feet, given by Decker in *Circular 15*, is evidently a misprint, for the unit is only 519 feet thick.

A fourth collection taken about 730 feet below the graptolite zone, near the base of Decker's Unit 184, yielded a number of cephalopods which Ulrich identified in the field as being similar to, if not identical with, forms from the Van Buren of Missouri (*Burenoceras*, *Dakeoceras*, et cetera). Unfortunately this collection was lost in transit and we have been unable to duplicate it.

A fifth collection, made about 15 feet below the cephalopod bed, contains a large number of gastropods, many of which are specifically identical with forms from the Van Buren. The following have been recognized.

Sinuopea umbilicata Ulrich and Bridge
Sinuopea basiplanata Ulrich and Bridge
Sinuopea, 2 or 3 undescribed species, all of which are identical with forms from Missouri

All five of these faunas can be correlated with a fair degree of certainty with faunas in strata in other parts of the Mississippi Valley which are cus-

[5] E. O. Ulrich and A. F. Foerste, "New Genera of Ozarkian and Canadian Cephalopods," *Bull. Dennison Univ., Jour. Sci. Labs.*, Vol. 30 (1935), pp. 259–90.

tomarily classed as Lower Ordovician. The three upper faunas are correlated with the Gasconade of Missouri and the Oneota of the Upper Mississippi Valley, whereas the two lower ones are correlated with the Van Buren of Missouri.

The genera *Hystricurus*, *Eremoceras*, and *Ophileta* are common forms in Lower Ordovician faunas but are as yet unknown in rocks of unquestioned Cambrian age. *Albertoceras* has recently been described from the Mons of British Columbia. *Symphysurina* is common to the Mons and to the Oneota. The remaining genera, *Sinuopea*, *Pelagiella*, and *Finkelnburgia*, are long ranging forms found in both Upper Cambrian and Lower Ordovician strata.

The Van Buren fauna which marks the base of the Ordovician in Missouri is notable for the sudden appearance of cephalopods[6] associated with various species of *Sinuopea* and other gastropods. This same association occurs in the Arbuckle limestone. The species of gastropods found in this zone of the Arbuckle are identical with the Missouri forms, and the cephalopods belong to genera which are abundant in the Van Buren and which are unknown below it.

These correlations still leave much to be desired, but they are based on reasonably good collections, and many of the forms identified are widely distributed geographically, and at the same time have very short vertical ranges.

The graptolites, on the other hand, all belong to the very primitive order *Dendroidea*, and to genera which for the most part are long ranging, which change very slowly, and which are extremely difficult to identify specifically unless one has an abundance of well preserved material. These particular forms are not well adapted to serve as index fossils, and since the testimony of the other groups of invertebrates is consistent, it is my opinion that it far outweighs that of the graptolites, and they should not be considered the determining factor in making age assignments.

On the basis of the correlations here indicated, the base of the Ordovician must be drawn below the Van Buren faunas, which would place it at least 750 feet below the graptolite zone or about 4,680 feet below the top of the Arbuckle limestone (about the base of Decker's Unit 184, or 5,636 feet below the top, according to his measurements).

Decker has recently subdivided the Arbuckle limestone into a number of units, but the published digest of his paper does not give much idea of the boundaries of his subdivisions.[7]

The Honey Creek, Fort Sill, Royer, and Signal Mountain formations had previously been described by Ulrich.[8] The names Chapman Ranch and McKenzie Hill, the former from Chapman's Ranch on Highway 77 and the latter from a small hill south of Signal Mountain, near Fort Sill, Oklahoma, have never been defined, although Ulrich has used them repeatedly in correspondence and manuscript. The sequence and approximate position of these units is shown in Figure 1. In describing fossils from Missouri, Ulrich and I[9]

[6] Josiah Bridge, "Geology of the Eminence-Cardareva Quadrangles," *Missouri Geol. Survey Bull. 24* (1930), pp. 106–07.

[7] Glenn S. Dille, digest of paper by C. E. Decker, "The Early Paleozoic Stratigraphy of the Arbuckle and Wichita Mountains," *Tulsa Geol. Soc. Digest* (1933), pp. 55–57.

[8] E. O. Ulrich, "Preliminary Description of the Honey Creek, Fort Sill, Royer, and Signal Mountain Formations of Oklahoma," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 742–47.

[9] E. O. Ulrich and Josiah Bridge, *Missouri Geol. Survey Bull. 24* (1930), p. 195

stated that some of the species also occur in Ulrich's proposed Chapman Ranch formation, and also that the Chapman Ranch is in part the equivalent of the Van Buren. Ulrich now considers the Chapman Ranch formation to be the exact equivalent of the Van Buren. This would restrict it to the 144 feet of beds in Decker's Unit 184, and possibly some of Unit 183. Ulrich has always used the name McKenzie Hill to denote limestones in the Arbuckle and Wichita Mountains which carry the Gasconade fauna, and in this section the

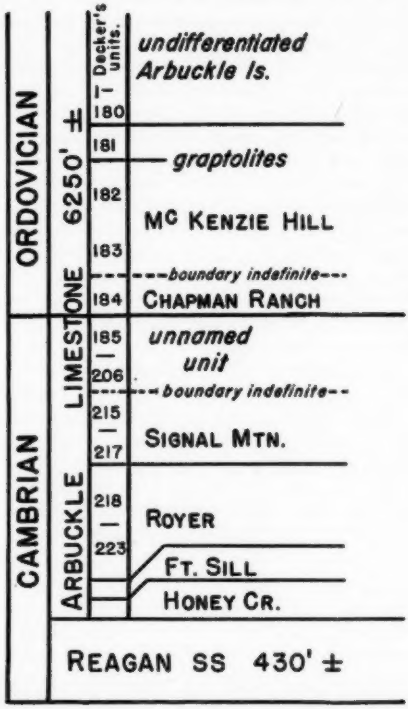

FIG. 1.—Columnar section showing position of graptolite bed in Arbuckle limestone with respect to various numbered and named units discussed in this article. Correlation of numbered units with named units below No. 183 is purely tentative. Above Unit 181, diagram is not to scale; below Unit 181, thicknesses of various units are indicated in their proper proportions.

name should be applied to Decker's Units 181, 182, and possibly 183. The contact between the two has not been satisfactorily established in this section.

The highest zone in the Arbuckle limestone of this section which is definitely Cambrian occurs much lower down in the section, 5,375 feet below the top of the formation and about 1,300 feet above the porphyry. This fauna is a typical Upper Cambrian assemblage characterized by the genera *Eurekia*, *Stenopilus*, *Euptychaspis*, and *Plethometopus*. It strongly suggests the *Eurekia*

zone at the base of the Norwalk sandstone of the Upper Mississippi Valley and is tentatively correlated with that horizon. In Wisconsin this bed immediately overlies the Lodi shale, which carries the graptolite fauna described by Ruedemann.

The 700 feet of strata lying between this zone and the Van Buren zone have yielded only one fauna which has come to my attention. This occurs in a limestone about 220 feet above the *Eurekia* bed and 500 feet below the Van Buren zone. The fauna consists of a brachiopod and a trilobite, both of which are undescribed. Their exact equivalents are not known in other areas, but their affinities are with the late Upper Cambrian.

The faunal evidence indicates that the Cambrian-Ordovician boundary probably comes somewhere in the interval between this last fossil bed and the Van Buren zone. The Van Buren zone is the oldest Ordovician fauna known in the Mississippi Valley, but several Cambrian faunas overlie the *Eurekia* zone in Wisconsin, and one or more of these may be present in the 700 feet of strata which has yielded so few fossils up to the present time.

Below the *Eurekia* zone is a series of Upper Cambrian faunas, many of which are known from Texas, Missouri, Wisconsin, and elsewhere. The lowest of these is the well known and widely distributed *Camaraspis* zone. This occurs in the base of the Honey Creek limestone and serves to correlate this portion of it with the base of the Wilberns of Texas, the base of the Davis of Missouri, the Ironton member of the Franconia of the Upper Mississippi Valley, and with many other units.

The exact placing of the boundary between the Cambrian and the Ordovician will have to await more detailed work, but for the present I would draw it at the contact of the smooth-weathering limestones carrying the Van Buren fauna and the rough-weathering, craggy dolomites which immediately underlie this zone, in other words, at the base of Decker's Unit 184.

If this boundary is used the thickness of the Cambrian portion of this section is about 2,000 feet, including about 400 feet of Reagan sandstone, and the Ordovician portion totals about 4,700 feet.

JOSIAH BRIDGE

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D. C.
April 30, 1936

PETROLEUM GEOLOGY OF GONDWANA ROCKS OF SOUTHERN BRAZIL

Victor Oppenheim, in his very fine paper, "Petroleum Geology of Gondwana Rocks of Southern Brazil," in the *Bulletin* of December, 1935, gives a short note on Madagascar (p. 1779). Apparently he quotes from memory for he does not refer to the source of his information (*Jour. Inst. Petrol. Tech.* (London), Vol. 15, No. 72). He states that "Several active exudations are known in the western part of the island. These are derived from Tertiary deposits and, according to Wade, are the distillation product of the carbonaceous rocks of this age." He goes on to say that "Jurassic and Triassic beds containing as much as 10 per cent of bitumen exist in certain localities," and so on.

Now the paper referred to makes it clear that the oil exudations and im-

pregnations in western Madagascar are not derived from the Tertiaries. There are no Tertiary deposits in the vicinity. The occurrences are confined entirely to the Triassic rocks with, perhaps, one exception in the southwest where seepages are reported to occur in strata which are regarded as belonging to the underlying Permian. I know of no well authenticated seepages in association with the Jurassic or younger groups in Madagascar.

Later (p. 1780), in dealing with New South Wales, he writes of the Bulli (not "Bully") seam as being highly saturated with bitumen. Now I am one of those who refuse to believe that kerosene shales contain bitumen. Liquid hydrocarbons can be obtained from such shales by distillation. One might as well say that malt and hops contain beer because beer can be produced from them. The late Professor T. W. Edgeworth David was the authority on the coal basins of New South Wales. In his latest work, "Notes to a Geological Map of Australia" (1932), he devotes several sections to coal, oil shales, and mineral oil (pp. 122–36). As with myself, he apparently did not know that the Bulli seam was "highly saturated with bitumen."

Finally, the paragraph concerning Balmain and Sydney should come under the heading, *New South Wales*, not under *Queensland*. Sydney is the Seat of Government and capital city of New South Wales.

ARTHUR WADE

PERTH, WESTERN AUSTRALIA
April 23, 1936

CONROE OIL FIELD, TEXAS

In their recent paper Michaux and Buck[1] continued an error which should be corrected before it becomes too widespread in the literature, and before it causes erroneous correlation. On page 745 they cited *Operculina oliveri* as the most important of the *Foraminifera* in the green-sand marl 30 feet from the base of the "Caddell" formation, Jackson Eocene. On page 744 they figured an *Operculina* which they labeled *Operculina oliveri*, and which appears to be a reproduction of a figure previously published by Ellisor.[2] The identification of this *Foraminifera* as *Operculina oliveri* Cushman was first published by Ellisor.[3]

Operculina oliveri was described by Cushman "from the Eocene deposits of Moctezuma at the second large bend above its entrance into Panuco River, Mexico." From the associated fossils at the type locality as well as its occurrence in Texas,[4] *Operculina oliveri* Cushman is a Middle Claiborne fossil.

The *Operculina* from the Moody's Branch cited in Ellisor's two papers as *Operculina oliveri* Cushman is not *Operculina oliveri* Cushman but *Operculina vaughani* Cushman.[5] *Operculina vaughani* Cushman is a fairly common species

[1] F. W. Michaux, Jr., and E. O. Buck, "Conroe Oil Field, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 6 (June, 1936), pp. 736–99.

[2] Alva C. Ellisor, "Jackson Group of Formations in Texas with Notes on Frio and Vicksburg," *ibid.*, Vol. 17, No. 11 (November, 1933), Pl. 2, Fig. 15.

[3] Alva C. Ellisor, *op. cit.*, p. 1301, p. 1320, Pl. 2, Fig. 15.

[4] The writers are preparing a paper on the larger *Foraminifera* of the Claiborne of the Gulf Coast and their correlation.

[5] Donald W. Gravell and Marcus A. Hanna, "Larger Foraminifera from the Moody's Branch Marl, Jackson Eocene, of Texas, Louisiana, and Mississippi," *Jour. Paleon.*, Vol. 9, No. 4 (1935), p. 334.

in the basal Jackson green-sands of eastern Texas, Louisiana, and Mississippi and is associated with *Camerina moodybranchensis* Gravell and Hanna, *Camerina jacksonensis* Gravell and Hanna, *Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman, and *Discocyclina flintensis* (Cushman). *Operculina vaughani* Cushman has not been found in association with *Operculina oliveri* Cushman, nor has *Operculina oliveri* Cushman been found in the basal green-sands of the Jackson.

The statement that "the most important [marker] of which is *Operculina oliveri* [*Operculina vaughani* Cushman]"[6] is hardly correct inasmuch as throughout eastern Texas and western Louisiana in the basal Jackson green-sands *Camerina moodybranchensis* is considerably more abundant, and owing to its heavier test it is better preserved in well cuttings. For these reasons *Camerina moodybranchensis* is a better index fossil for this horizon than *Operculina vaughani* Cushman, although the two occur together.

DONALD W. GRAVELL and MARCUS A. HANNA

HOUSTON, TEXAS
June 17, 1936

[6] F. W. Michaux, Jr., and E. O. Buck, *op. cit.*, p. 745.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 7 (JULY, 1936), PP. 987-993

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and are available to members and associates.

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*"Fosseis do Devoniano do Paraná" (Some Fossils of the Devonian of Paraná). By VICTOR OPPENHEIM. *Annaes Acad. Brasileira Sci.* (Rio de Janeiro, Brazil), Vol. 7, No. 4 (December 31, 1935), pp. 345–48; 5 figs.

This paper refers to some fossil plant remains found by the writer in the Devonian shales near Tibagy, Paraná, Southern Brazil. These remains, though badly preserved, are similar to plants found and described by Anderson and Halle on the Falkland Islands where they are attributed to the phylum *Pteridophitae.* Similar fragments of fossil plants from the Devonian were also reported to the writer by E. Terra Arocena from a well drilled in Uruguay.

These new fossils are the first of the kind found in the Eo-Devonian of Southern Brazil.

V. OPPENHEIM

RIO DE JANEIRO, BRAZIL
MARCH 29, 1936

"Neue Cephalopoden aus der oberen Kreide vom Rio Grande del Norte (Mexico und Texas)" (New Cephalopods of the Upper Cretaceous of the Rio Grande Area of Mexico and Texas). By HANS H. RENZ. *Abhandlungen Schweizerischen Palaeontologischen Gesellschaft,* Bd. 57 (1936). 4 pls., 1 sketch map. Introduction by W. Staub.

This publication describes and figures two new species and two new varieties of ammonoids from the Austin chalk. A new species is also described from the Escondido. In each case the specimens came from the Mexican side of the Rio Grande opposite Maverick County, Texas, and a sketch map is presented showing the localities. Lists of fossils are given from the same areas and horizons as these new species.

A correlation table is included showing the relationship of the Cretaceous and Eocene beds in Mexico to the strata in Texas. The author correlates the Cárdenas beds of Mexico with the Santonian and the upper Austin chalk and lower Taylor of Texas. Present knowledge indicates that the Cárdenas beds are Maestrichtian in age or equivalent to the Navarro of Texas. The line showing the unconformity between the Méndez and Tamesí (Velasco) formations in Mexico has, inadvertently, been carried through horizontally, on the chart, so that it underlies the Escondido, whereas, the hiatus represented by this line is post-Escondido; it should be placed higher in the time scale for the Rio Grande and Texas regions. The relationship of these beds is shown more correctly by Adkins in "Geology of Texas," *Univ. of Texas Bull. 3232* (1932), p. 263.

JOHN M. MUIR

FORT WORTH, TEXAS
April 13, 1936

RECENT PUBLICATIONS

AFRICA

*"Recherches de pétrole aux colonies" (Petroleum Investigations in the Colonies), by M. M. Mercier. *Assoc. Français Tech. Pétrole Bull. 34* (January–March, 1936), pp. 9–26; 6 illus.

*"Note sur l'état, fin 1935, des recherches de pétrole au Maroc" (Note on Status of Petroleum Investigations in Morocco at End of 1935). *Ibid.*, pp. 27–29.

*"Les gisements de pétrole au Maroc" (Oil-Bearing Beds of Morocco), by Ch. Baron. *Ibid.*, pp. 30–36.

*"Premières recherches de pétrole sur la côte atlantique du territoire du protectorat espagnol au Maroc" (Preliminary Petroleum Investigations on the Atlantic Coast of the Spanish Protectorate in Morocco), by A. Marin, J. L. Pastora and J. de Lizaur. *Bull. Soc. Geol. France*, Ser. 5, Vol. IV, Nos. 8–9 (1935), pp. 649–74; 3 figs., 2 pls. In French.

ARGENTINA

*"Las fallas de Comodoro Rivadavia en los estratos petroliferos y en los afloramientos" (The Faults of Comodoro Rivadavia in the Petroliferous Strata and in the Outcrops), by Enrique Fossa-Mancini. *Bol. Inform. Petrol.* (Buenos Aires), Vol. 12, No. 136 (December, 1935), pp. 65–95; 15 figs.

ARIZONA

*"Correlation of Arizona Paleozoic Formations," by A. A. Stoyanow. *Bull. Geol. Soc. America*, Vol. 47, No. 4 (April 30, 1936), pp. 459–540; 5 figs., 1 pl.

CALIFORNIA

*"Present Oil Supply in California," by Harold W. Hoots. *Oil and Gas Jour.*, Vol. 35, No. 1 (May 21, 1936), p. 65; 3 figs.

*"Report on Newhall Oil Field," by R. W. Walling. *California Dept. Nat. Resources, California Oil Fields* (San Francisco), Vol. 20, No. 2, October, November, December, 1934 (1936), pp. 5–58; 4 pls.

CANADA

*"The West Half of Wildcat Hills Map-Area, Alberta," by G. S. Hume. *Geol. Survey Canada Mem. 188* (1936). Oil and gas prospects, pp. 11–15. 15 pp., 2 maps, 2 pls., 2 figs. Price, 10 cents.

*"Limestones of Canada, Part III (Quebec)," by M. F. Goudge. *Canada Dept. Mines Rept. 766* (Ottawa, 1935). 275 pp. 36 pls., 13 figs. Price, 50 cents.

COLORADO

*"A Brief Review of the Geology of the San Juan Region of Southwestern Colorado," by W. Cross and E. S. Larsen. *U. S. Geol. Survey Bull. 843* (1935), vi and 138 pp. Supt. Documents, Washington, D. C. Price, $1.00.

ENGLAND

*"The Flora of the London Clay," by W. N. Edwards. *Proc. Geol. Assoc.* (London), Vol. 17, Pt. I (March 27, 1936), pp. 22–31; 3 figs.

GENERAL

Oil and Petroleum Year Book, 1936, compiled and published by Walter E. Skinner. 27th ed., 1936. 464 pp. 5.25×8.25 inches. Cloth. Particulars about 680 companies engaged in producing, carrying, and marketing oil. Statistics on world production for 9 years ended December, 1935. Trade names. Glossary of 136 technical terms. Walter E. Skinner, 15, Dowgate Hill, Cannon Street, London, E. C. 4. Price, 11s. net, post-free abroad.

"Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," by A. A. Baker, C. H. Dane, and J. B. Reeside, Jr. *U. S. Geol. Survey Prof. Paper 183* (1936). v, 66 pp.; 26 pls., 16 figs. Available from Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.50.

*"The Status of the Name 'Valentine" in Tertiary Geology and Paleontology," by F. Walker Johnson. *Amer. Jour. Sci.*, Vol. 31, No. 186 (June, 1936), pp. 467–75; 2 figs.

*"A Monograph on the Orbitoididae, Occurring in the Tertiary of America," by W. A. E. Van de Geyn and I. M. Van der Vlerk. *Leidsche Geol. Mededeelingen*, Deel VII, Aflevering 2, XII (1935), pp. 221–72; 81 illus., 1 map.

**Gorman's Petroleum Directory of Oklahoma* (*1936*), by B. R. Gorman, Box 395, Tulsa. Price, $1.00. Paper. List of all companies and individuals in Oklahoma, connected with production of petroleum.

*"Erdöl" (Petroleum), by Karl Krejci-Graf. *Verständliche Wissenschaft* (Popular Science), Vol. 28. 162 pp., 30 figs. Julius Springer (Berlin, 1936).

Down to Earth: An Introduction to Geology, by Carey Croneis and William C. Krumbein. Pp. xviii+501; illus. University of Chicago Press. Price, $3.75.

Mineral Yearbook, 1935, O. E. Kiessling, compiler. U. S. Bur. Mines (Washington, 1935). Price, $2.00. The valuable compilation of statistics formerly published as "Mineral Resources." A chapter on world production and international mineral policies is of general interest.

*"Die Entstehung des Erdöls" (Origin of Petroleum), by Karl Krejci-Graf. *Kali* (Wilhelm Knapp, Halle, Saale), Vol. 30, No. 6 (March 15, 1936), pp. 51–54; No. 7 (April 1, 1936), pp. 63–66; 5 illus.; No. 8 (April 15, 1936), pp. 74–77; 1 illus.; No. 9 (May 1, 1936), pp. 84–87; No. 10 (May 15, 1936), pp. 91–94. In German.

*"Gravitational Compaction of Clays and Shales," by Hollis D. Hedberg. *Amer. Jour. Sci.* (New Haven, Connecticut), Vol. 31, No. 184 (April, 1936), pp. 242–87; 7 figs.; list of 88 refs.

**Tertiary Faunas. Vol. I. The Composition of Tertiary Faunas*, by A. Morley Davies. 406 pp., 565 figs. Cloth. Thomas Murby and Company, 1 Fleet Lane, London, E. C. 4. Price: 22s, 6d, net. Price corrected from notice printed in March and April *Bulletins*.

Internationaler Geologen und Mineralogen-Kalender für die Jahre 1937–1938 (International Directory of Geologists and Mineralogists for 1937–38). Prepared by E. Beyenburg. Published by the German Geological Society, Berlin. Printed by Ferdinand Enke, Stuttgart, W., Germany. Contains names and addresses of individual geologists, State and national surveys, geological schools, laboratories, institutions, associations, et cetera. Approx. 530 pp. Price, RM 10. To be ready late in 1936.

*"Bibliography of North American Geology, 1933 and 1934," by Emma M. Thom. *U. S. Geol. Survey Bull. 869* (1936). 389 pp.

*"Methods of Estimating Underground Reserves," by V. Bilibin. *Oil Weekly*, Vol. 81, No. 7 (April 27, 1936), pp. 33–34; 2 tables. Part I only—Parts II and III will appear in early issues. Method approved for use at 17th International Geological Congress at Moscow, August, 1937.

*"A Theoretical Examination of Straight-Hole and Direct-Drilling Technique," by L. V. W. Clark. *Jour. Inst. Petrol. Tech.* (London), Vol. 22, No. 149 (March, 1936), pp. 140–65; 7 illus.

*"Origine et tectonique des terrains salifères et pétrolifères" (Origin and Tectonics of Saliferous and Petroliferous Beds), by Horace Havre. *Rev. Petrol.* (Paris), No. 678 (April 11, 1936), pp. 551–54; 1 illus. In French.

Principes de géologie du pétrole (Principles of the Geology of Petroleum), by J. Jung. Ch. Beranger, 15 Rue des Saints-Pères, Paris et Liege (1935). 1 vol., 184 pp., 50 figs. Price, 34 fr.

Erdöl-Muttersubstanz (Origin of Petroleum), by F. E. Hecht and others. Ferd. Enke, Stuttgart (1935), 181 pp., 25 figs. Price, 17 RM. Reviewed in *Econ. Geol.*, Vol. 31, No. 3 (May, 1936), pp. 321–22.

INDIA

*"De Pretertiaire Historie van den Indischen Archipel" (Pre-Tertiary History of the Indian Archipelago), by J. H. F. Umbgrove. *Leidsche Geol. Mededeelingen*, Deel VII, Aflevering 1, IX (1935), pp. 119–55; 6 figs.

LOUISIANA-TEXAS

**Oil and Gas Journal*, Vol. 34, No. 48 (April 16, 1936), the Gulf Coast number, contains articles which are of interest to geologists, several of which are listed here.

"Louisiana Petroleum Stratigraphy," by Henry V. Howe; 9 figs., 2 tables.

"Geophysical Generalities," by Robert P. Clark; 3 illus.

"Possibilities of Shoreline or Shoestring Fields on Gulf Coast," by John F. Weinzierl; 9 figs.

"The Rodessa Field," by John S. Ivy; 10 pls.

"Interesting Features in Somerset Field, One of Country's Big Shallow Pools," by Richard A. Jones; 1 illus.

MISSISSIPPI

*"The Geologic History of the Vicksburg National Military Park Area," by William Clifford Morse. *Mississippi State Geol. Survey Bull. 28* (1935). 20 pp., 1 pl., 6 figs.

*"A Preliminary Investigation of the Bleaching Clays of Mississippi," by Harry X. Bay. *Ibid., Bull.* 29 (1935). 62 pp., 1 pl., 4 figs.

*"The Eocene Sediments of Mississippi," by Ralph Early Grim. *Ibid., Bull. 30* (1936). 240 pp., 66 histograms, 3 pls., 25 figs.

OKLAHOMA

*"Ardmore District Has Great Prospects for Future Oil Development," by C. W. Tomlinson. *Oil and Gas Jour.*, Vol. 34, No. 47 (April 9, 1936), pp. 32–34; 5 illus.

PENNSYLVANIA

*"Continental Upper Devonian of Northeastern Pennsylvania," by Bradford Willard. *Bull. Geol. Soc. America*, Vol. 47, No. 4 (April 30, 1936), pp. 565–608; 3 figs., 3 pls.

RUSSIA

The following references have been translated from the Russian titles by Basil B. Zavoico.

*"Five Years of Electrical Exploration," by D. Jabreff. *Azerbaijan Oil Industry* (Baku), Nos. 10–11 (1935), pp. 9–11.

*"Exploration for Oil with Electrical Methods," by L. Gorbenko. *Ibid.*, pp. 11–15; 14 figs.

*"Use of Electrical Surveys of Oil Wells in Estimating Reserves," by I. Kogan. *Ibid.*, pp. 15–20; 3 maps, 3 illus.

*"Variables Results Secured in Electrical Surveys of Same Oil Wells," by S. Komanoff and D. Jabreff. *Ibid.*, pp. 20–32; 12 log surveys and other illus.

*"Practical Uses of Electrical Surveys of Oil Wells in Baku Oil Fields To-Day," by V. V. Denisevich. *Ibid.*, pp. 32–35; 2 maps and 1 log survey.

*"Petrography of the Productive Measures (Pliocene) of the Eastern Kabristan," by G. Fuks-Romanoff. *Ibid.*, pp. 42–49; 2 tables, 2 maps, 2 photomicrographs.

*"Development and Exploration of the Pre-Kirmaku Formation in the Proved Fields of the Apsheron Peninsula," by V. V. Bilibin. *Ibid.*, pp. 49–51.

*"Paleogene Formations of Northern Caucasus and Problems of Their Studies in the Future," by K. A. Prokopoff. *Oil Industry* (Moscow), No. 2 (1936), pp. 24–27.

*"New Data on Tectonics of Southern Kakhetia," by S. G. Bukia. *Ibid.*, pp. 27–32; 1 map.

*"The Methods of Development in the Northeast Caucasus," by I. O. Brod. *Ibid.*, No. 3 (March, 1936), pp. 17–25; 4 maps, 4 cross sections.

*"The Problems of Ural-Emba Oil District," by S. P. Kiselev. *Ibid.*, pp. 25–34.

*"The Oil Possibilities of Karnap-Choul Steppes" (East Uzbekistan), by N. I. Bilalov. *Ibid.*, pp. 34–39.

*"The Zikh Oil Field," by A. I. Mesropian. *Azerbaijan Oil Industry* (Baku) No. 12 (December, 1935), pp. 10–14; 1 map.

*"Exploration Methods in Nefte-Chala," by P. I. Levitski. *Ibid.*, pp. 14–20; 1 map, 1 cross section.

*"The Facies and the Oil Possibilities of the Maikop Series in the Pre-Caspian Region," by A. Ali-Zade. *Ibid.*, pp. 22–26.

SOUTH AMERICA

*"Documentation géologique sur les pays pétrolifères de l'Amérique du Sud et des îles de l'archipel des Caraibes" (Geology of the Petroliferous Regions of South America and the Caribbean Archipelago). Part II. "Introduction à la geologie du Venezuela et bibliographie geologique" (Introduction to the Geology of Venezuela and Geological Bibliography), by H. de Cizancourt and D. Schneegans. *Annal. Nat. Combust. Liquides* (Paris), Vol. 11, No. 1 (January–February, 1936), pp. 93–126.

SOUTH CAROLINA

"Geology of the Coastal Plain of South Carolina," by C. Wythe Cooke. *U. S. Geol. Survey Bull. 867* (1936), v, 196 pp.; 18 pls. (including 10 maps), 2 figs. Available from Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.60.

TEXAS

*"Plymouth Area Reserves," by Leavitt Corning, Jr. *Oil Weekly* (March 30, 1936), pp. 30, 32–34; map and section.

*"Geology and Economic Significance of East Texas," by Basil B. Zavoico. *World Petroleum* (New York, March, 1936), pp. 94–135; 41 illus., 13 tables.

TURKEY

**Maden Tetkik ve Arama Enstitüsü Yayini* (Mineral Investigation and Exploration Institute of the Turkish Government, Ankara), Vol. 1, No. 1 (March, 1936). 42 pp., illus. A new Turkish journal containing news and data of mineral resources including petroleum. In Turkish.

UTAH

"The Book Cliffs Coal Field in Emery and Grand Counties, "Utah," by D. Jerome Fisher. *U. S. Geol. Survey Bull. 852* (1936). iv, 104 pp.; 15 pls. (including 5 maps), 2 figs. Available from Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.75.

"Geology of the Salt Valley Anticline and Adjacent Areas, Grand County, Utah," by C. H. Dane. *Ibid., Bull. 863* (1935). v, 184 pp.; 21 pls. (including 3 maps), 4 figs. Supt. Documents, Washington, D. C. Price, $1.00.

"Geology of the Monument Valley-Navajo Mountain Region, San Juan County, Utah," by Arthur A. Baker. *Ibid., Bull. 865* (1936). vi, 106 pp.; 17 pls. (including 3 maps), 3 figs. Supt. Documents, Washington, D. C. Price, $0.60.

WYOMING

*"Study in the Jurassic of Wyoming," by C. H. Crickmay. *Bull. Geol. Soc. America*, Vol. 47, No. 4 (April 30, 1936), pp. 541–64; 3 pls.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Forth Worth, Texas), Vol. 10, No. 2 (March, 1936).

"Schwagerina verus Pseudoschwagerina and Paraschwagerina," by Carl O. Dunbar and John W. Skinner.

"Actinopterygian Jaws from the Mississippian Black Shales," by Chalmer L. Cooper.

"Fusulinids from the Black Hills and Adjacent Areas in Wyoming," by M. L. Thompson.

"Ostracoda from the Chouteau Formation of Missouri," by Philip S. Morey.

"Some Fusulinid Problems," by M. P. White.

"Rudistids from the Cretaceous of Northern Santa Clara Province, Cuba," by M. G. Rutten.

**Journal of Paleontology* (Fort Worth, Texas), Vol. 10, No. 3 (April, 1936).

"Cambrian and Lower Ordovician Trilobites from Northwestern Canada," by Teiichi Kobayashi.

"Stratigraphic Significance of Miocene, Pliocene, and Pleistocene Pectinidae in the Southeastern United States," by Wendell C. Mansfield.

"The Fusulinid Genus Verbeekina," by M. L. Thompson.

"Two New Insectivores from the Lower Paleocene of New Mexico," by T. Emmett Reynolds.

"New Cambrian Brachiopods from Alaska," by G. Arthur Cooper.

"A Devonian Flora from Kentucky," by Charles B. Read.

**Journal of Sedimentary Petrology* (Fort Worth, Texas), Vol. 6, No. 1 (April, 1936).

"Heavy Mineral Zones in the Modelo Formation of the Santa Monica Mountains, California," by William M. Cogen.

"Dominant Factors in the Formation of Firm and Soft Sand Beaches," by E. M. Kindle.

"Notes on the Dielectric Separation of Mineral Grains," by Gilman A. Berg.

"Barite Concretions from the Yazoo Clay, Eocene, of Louisiana," by Marcus A. Hanna.

"Mineral Study of Kiamichi Formation of West Texas," by Raymond Sidwell.

"Application of Logarithmic Moments to Size Frequency Distributions of Sediments," by W. C. Krumbein.

ASSOCIATION DIVISION OF GEOPHYSICS

**Geophysics* (Denver, Colorado), Vol. 1, No. 2 (June, 1936).

"The Organization of an Effective Exploration Department," by B. B. Weatherby.

"A Proposed Geophysical Program of Exploration for Nebraska and the Dakotas," by J. H. Wilson.

"Electrical Earth Transients in Geophysical Prospecting," by L. Statham.

"A Refraction and Reflection Fan to 187.8 Kilometers," by L. D. Leet.

"Explosives for Seismic Prospecting," by N. G. Johnson and G. H. Smith.

"Relation between Firing Current and Performance in Seismograph Caps," by L. A. Burrows.

"Significance of Some Fundamental Properties of Explosives, with Special Reference to Geophysical Prospecting," by H. E. Nash and J. M. Martin.

"Note on Reflections from Steeply Dipping Beds," by C. A. Heiland.

"An Experimental Study of the Elastic Properties of Rocks," by John M. Ide.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 7 (JULY, 1936), PP. 994-995

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 7 (JULY, 1936), PP. 996-998

Memorial

L. G. PUTNAM

L. G. Putnam was born in Salt Lake City, Utah, on July 26, 1898. He lost his life in an airplane crash near Bulawayo, Southern Rhodesia, on March 26, 1936.

Subsequent to 1912, he lived in southern California, and in 1922 graduated from the University of California. Immediately thereafter he went to Tampico, Mexico, where he joined the geological staff of the International Petroleum Company, with whom he remained until November, 1924. Between November, 1924, and April, 1925, he was a field geologist with the East Coast Oil Company in the Tampico district. During April, 1925, he was employed by the Mexican Gulf Oil Company and remained with that company in the capacity of field geologist until February, 1929, when he was transferred to the Western Gulf Oil Company of California and was engaged there until 1931. Thereafter he resided in Carlsbad, New Mexico, where he was employed by a potash company.

In 1934 he went to Portugese East Africa to do geological work for the Inyaminga Petroleum Company, a South African organization which is conducting coal and oil explorations on a large concession. By the end of 1935 he had already extended his investigations over a large area situated near the mouth of Zambezi River, and had submitted a detailed geological report which led to starting a test well.

At the time of his death he was en route from the field to headquarters at Johannesburg. The plane, a Waco four-seater, was piloted by Rodwell King, an experienced pilot with a long record of safe flying. A farmer who saw the accident stated that a wing collapsed while the machine was flying fast and low. Though the fuel tank broke away before the plane hit the ground the wreckage went up in flames. The pilot was trapped in the plane but Putnam was thrown clear and death was instantaneous.

Many years ago, Putnam married Miss Alice Gower of Los Angeles. There are no children. She was in South Africa at the time of his death and will continue to reside there for the present. His mother, Mrs. N. A. Putnam, resides at 326 North Camden Drive, Beverley Hills, California.

Putnam was a diligent and intelligent worker with a good mind as those will testify who know of his work and reports. All will feel that his untimely death is a loss to the profession.

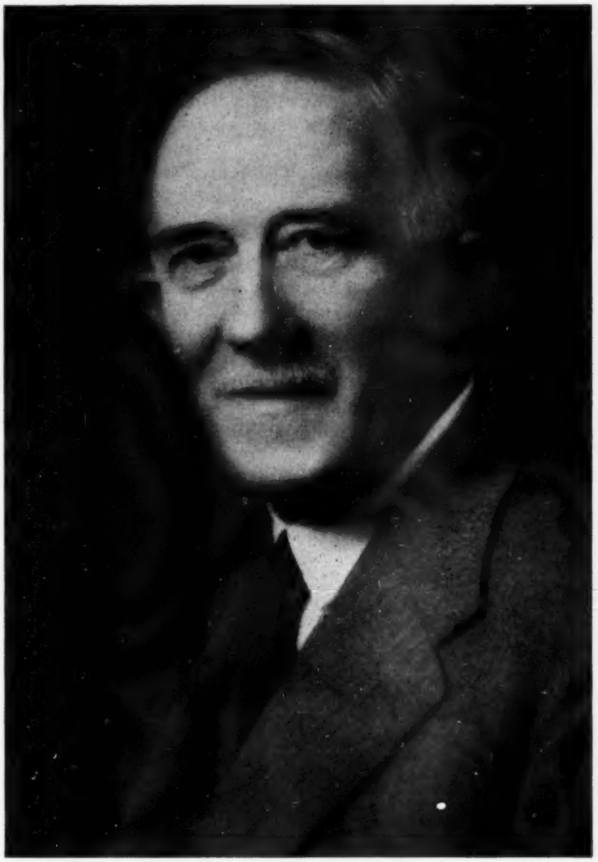
He had a faculty for making friends and, among the many who knew him intimately, was known as "Put." A host of them in California and elsewhere will deeply regret his passing.

D. DALE CONDIT

SYDNEY, AUSTRALIA
April 27, 1936

CONRAD SCHLUMBERGER

Conrad Schlumberger died on May 9, in Stockholm, of a cerebral hemorrhage, after a very short illness. He was born in Guebwiller, Alsace, in 1878. He successively attended in Paris the École Polytechnique and the École Nationale Supérieure des Mines, from which he was graduated in 1904 as a



Conrad Schlumberger

State mining engineer (Corps des Mines). In 1906, he was appointed professor of physics at the School of Mines of St. Étienne, and in 1907, he received the same assignment at the École Supérieure des Mines in Paris, which he retained until the beginning of the World War. He gallantly took part in the whole World War as a captain and major in the French artillery. In 1919

he was reinstated professor of physics at the École Supérieure des Mines de Paris, which position he resigned in 1923 to devote himself entirely to activities in the field of applied geophysics.

It is for his research work, discoveries, and commercial success in this field that the name of Conrad Schlumberger is particularly known to the mining and geological profession at large. After several years of laboratory research work, he endeavored to apply his ideas and inventions to the solving of actual field problems of geology and tectonics. This practical phase was started in 1912, and as early as 1913 results of great economic value were achieved, such as the discovery of the Tilva Roch ore body on the properties of the Mines de Bor (Servia). In this respect he was indisputably a pioneer who laid the foundations of the then unknown art of applied geophysics.

After the war, Conrad Schlumberger and his associates, while remaining very active in the field of surface geophysical exploration, became interested in another phase of geophysical prospecting, namely, the study of the nature of the formations traversed by a drill hole, by means of physical measurements actually performed at depth in the drill hole. The usefulness of this type of investigation was soon demonstrated, in particular in connection with oil exploration and exploitation. At the present time, electrical logging is a regular feature of the drilling practice in the oil fields and is applied in almost every oil district of the world. The service rendered to the oil industry in efficiency and in saving of time and money is considerable, and Conrad Schlumberger's invention ranks among the few outstanding ones achieved in the field of oil production during the past 10 years.

Conrad Schlumberger was deeply interested in all questions pertaining to the oil industry. He was widely known for his competence in this field, and was an active member of the American Association of Petroleum Geologists and of the Institution of Petroleum Technologists.

The geophysical profession and the oil industry have sustained an irreparable loss in his passing.

E. G. Leonardon

Houston, Texas
May 27, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 7 (JULY, 1936), PP. 999-1004

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

BENJAMIN C. CRAFT, associate professor of petroleum engineering, Louisiana State University, presented a paper entitled "Oil and Gas Development in Louisiana During 1935" at the annual meeting of the American Institute of Mining and Metallurgical Engineers, New York, February 17–21.

WARREN B. WEEKS has been transferred from Shreveport to be district geologist for the Phillips Petroleum Company's Arkansas district. His new address will be Box 491, El Dorado, Arkansas.

R. O. RHOADES has been transferred from Pittsburgh, Pennsylvania, to the Kuwait Oil Company, Limited, Kuwait, Persian Gulf.

T. WAYLAND VAUGHAN is retiring as director of the Scripps Institution of Oceanography of the University of California. He will be succeeded by HARALD ULRIK SVERDRUP, Norwegian oceanographer and meteorologist. Professor Vaughan was presented the Agassiz Medal for eminence in the science of the sea at the annual meeting of the National Academy of Sciences held in Washington, April 27–29.

ELIOT BLACKWELDER, professor of geology and head of the department, Stanford University, has been elected a member of the National Academy of Sciences.

N. W. BASS of the United States Geological Survey, addressed the North Texas Geological Society on "The Shoe String Sands of Kansas and Northeast Oklahoma," May 8.

HAL P. BYBEE, geologist and mineralogist for the mineral leasing board of the University of Texas, with headquarters at San Angelo, has been appointed head of the department of geology for the University at Austin. BYBEE, who succeeds F. W. SIMONDS, will retain his position for the board, spending the summer months at the West Texas field office. J. N. GREGORY will be in charge of the San Angelo bureau during Bybee's absence.

J. E. BRANTLY, Drilling and Exploration Company, presented a paper on "Rotary-Drilling Practices" at the Division of Production of the American Petroleum Institute's sixth mid-year meeting at Tulsa, May 13–15. R. S. CHRISTIE, Amerada Petroleum Corporation, presented a paper on "Use of Recording Pressure Gages in Drill-Stem Tests." PARKER D. TRASK, United States Geological Survey, and W. ROSS KEYTE, American Petroleum Institute Research Fellow, presented a paper on "Degree of Reduction of Sediments in the East Texas Basin as an Index of Source Beds."

D. G. EMRICK, has changed his address from Houston, Texas, to Box 661, Tulsa, Oklahoma.

WILLIAM C. IMBT, formerly with the Illinois State Geological Survey, has accepted a position with the Stanolind Oil and Gas Company, Midland, Texas.

W. E. RENNIE, geologist, and SEWELL THOMAS, a Denver attorney, have organized Mineral Rights, Incorporated, to buy and sell royalties in eastern Colorado.

ROY P. LEHMAN has been transferred to the subsurface department of the Phillips Petroleum Corporation and is now located at Shawnee, Oklahoma.

HOWARD S. BRYANT, district geologist for Skelly Oil Company in Kansas, gave a paper dealing with the Cunningham field in Kingman and Pratt counties, Kansas, at a meeting of the Kansas Geological Society in Wichita.

WILLIAM L. HORNER, Core-Laboratories, Incorporated, Dallas, was the speaker at the weekly meeting of the Houston Geological Society, May 28; he also addressed the National Oil Scouts Association at its convention in Dallas, May 29-31. His subject was "Core Analysis as a Control to Well Completions."

IRA BRINKERHOFF has taken a position with the Stanolind Oil and Gas Company, Houston.

HARRY J. BROWN, Tulsa, and ALBERT S. CLINKSCALES and PAUL G. DARROUGH, Oklahoma City, have organized the Southwestern Drilling Company.

S. D. BUTCHER is in charge of the Turman Oil Company's new land and geologic headquarters in the Gulf Coast region. His office is in the Esperson Building, Houston, Texas.

DOUGLAS JOHNSON and ROBERT E. BATES presented a paper on "Correlation of Erosion Surfaces in Southwestern Wisconsin" at the recent Washington meeting of the National Academy of Sciences.

CONRAD SCHLUMBERGER, co-founder and president of the Schlumberger Well Surveying Corporation, died in Stockholm, Sweden, May 10, at the age of 58 years.

ROBIN WILLIS, geologist, Alberta, Canada, recently delivered a paper entitled "The Practical Problem of Finding Oil" before the mining bureau of the Board of Trade, Vancouver, British Columbia.

JOSEPH NEELY has changed his address to the Department of Geology, University of Wyoming, Laramie, Wyoming.

R. G. KURTZ, geologist with the Ohio Oil Company, Casper, Wyoming, has been transferred to Marshall, Illinois.

JOSEPH L. ADLER, geologist and geophysicist, president of the Pathfinder Prospecting Company, is moving his office from Houston, Texas, to 120 Broadway, New York City.

Ben H. Parker, geologist and mining engineer, Golden, Colorado, has had field headquarters in El Paso during the last six months, where he has been studying the special stratigraphic problems of the Gulf Oil Corporation of Pennsylvania.

E. E. Rosaire is president of the Independent Exploration Company, Houston, which specializes in seismic surveys. J. L. Adler is president of the subsidiary company, the Pathfinder Prospecting Company, Houston; J. H. Wilson is president of the subsidiary company, the Colorado Geophysical Corporation, Denver.

August Foerste, director of fossil research at the Smithsonian Institution at Washington, died April 24, at the age of 73 years.

Edward H. Perkins, head of the department of geology, Colby College, and since 1929 assistant State geologist of Maine, died April 13, at the age of 50 years.

Geological road logs of several of the principal highways through Oklahoma may be purchased from J. T. Richards, Gulf Oil Corporation, Ramsey Tower, Oklahoma City. This printed booklet of 68 pages, including the highway map of the state, was compiled and published by the Oklahoma City Geological Society.

Eugene G. Leonardon, vice-president of the Schlumberger Well Surveying Corporation, left Houston on June 12. His headquarters during the summer will be the Schlumberger organization in Paris, where he expects to study new lines of activity of the parent company and the application of electrical logging methods in foreign fields. Acting in Leonardon's capacity in Houston during the summer will be Paul Charrin, who was recently elected vice-president of the company.

A statement of the geology program in the National Parks, prepared by Earl A. Trager, chief geologist of the Naturalist Division of the Park Service, shows that many of the men associated with this project are members of the A. A. P. G. Trager is in charge of the work of conservation, education, and consultation directly under H. C. Bryant, assistant director of the Branch of Research and Education. The geologists in the Washington, D. C., office are: H. E. Rothrock, assistant chief; F. C. Potter, associate; E. R. Pohl, assistant. The United States is divided into four regions: I (New England, Appalachian, Atlantic, and Gulf Coast states, except Texas), George H. Chadwick in charge, Richmond, Virginia, and Harry S. Ladd, associate, Atlanta, Georgia, D. C. Hazlett, assistant, Cincinnati, Ohio, W. C. Dennis, junior geologist, Richmond; II (Great Lakes, Central Plains, and Rocky Mountain states east of Idaho and Utah), Carroll H. Wegemann in charge, Omaha, Nebraska, Chalmer H. Cooper, assistant, Chicago, Illinois, L. E. Kennedy, associate, Denver, Colorado, S. M. Anderson, assistant, Omaha; III (Arkansas, Oklahoma, Texas, New Mexico, and Arizona), Charles N. Gould in charge, Oklahoma City, Oklahoma, V. W. Vandiver, associate, Santa Fe, New Mexico, R. E. Maxwell, junior geologist, Big Bend, Texas; IV (Pacific states and Idaho, Utah, and Nevada), J. Volney Lewis in charge, San Francisco, California, Donald K. Mackay, associate, Portland, Oregon, Walter M. Chappell and Bruno C. Petsch, assistants, San Francisco.

The fourth annual Mineral Industries Conference of Illinois was held April 24 and 25 at Urbana, Illinois, sponsored by the Illinois State Geological Survey, the Engineering Experiment Station of the University of Illinois, and the Illinois Mineral Industries Committee. The theme was "Research on the State's Mineral Resources and Their Utilization." In the group of oil and gas researches in progress, the following papers were presented: "Underground Geology," by L. E. Workman and H. X. Bay; "Outcropping Strata," by J. M. Weller; "Repressuring and Water Flooding," by A. H. Bell; "Flow of Fluids through Oil Sands," by R. J. Piersol; "Education in Petroleum Engineering," by R. F. Larson. In the group of oil and gas researches needed, the following papers were presented: "Reserves and Underground Conditions," by William Bell; "Improved Oil Recovery," by Millard Flood; "Permeability of Oil Sands in Relation to Increased Recovery," by W. S. Corwin; "Acid Treatment," by Frederick Squires; "Imports and Exports and Domestic Industry," by W. H. Voskuil.

The first American meeting of the Institution of Petroleum Technologists (London) was held at the Mayo Hotel, Tulsa, May 15, in connection with the ninth International Petroleum Exposition. C. K. Francis made the local arrangements. Sixty-four attended the banquet. A. John Howarth came direct from London. E. DeGolyer and Gustav Egloff were the principal speakers.

Winthrop P. Haynes, of the Standard Oil Company of New Jersey, will soon return to the United States after many years in Paris and London. His residence is to be "Elmlea," Boxford, Massachusetts. His business address is 30 Rockefeller Plaza, New York City.

The Williams and Wilkins Company, Baltimore Maryland, are offering a cash award of $1,000 for the best manuscript on a science subject presented before July 1, 1937. The manuscript must be in English and "of a sort calculated to appeal to the taste of the public at large."

C. E. Needham, of the department of geology in the New Mexico School of Mines, Socorro, New Mexico, is giving the work in geology at the University of Mississippi during the summer session.

The Centenary of The Geological Survey of Pennsylvania was celebrated June 12 and 13, at Harrisburg. Following the official addresses, a symposium on "The Mineral Industry and the Geologic Survey" was presented. The following field conferences were arranged: (1) area north and west of Harrisburg; stratigraphy of Ordovician through Mississippian; Appalachian structure and physiography; (2) area southwest of Harrisburg; stratigraphy of Ordovician to Cambrian; pre-Cambrian volcanics; Triassic sediments and volcanics; (3) area east of Harrisburg; Ordovician stratigraphy and volcanics; Triassic sediments and volcanics; Cornwall magnetite deposits.

Theresa Louise Clark, wife of Frank Rinker Clark, chief geologist of the Marathon Oil Company, died after a brief illness at Tulsa, Oklahoma, May 25, 1936.

The third plenary World Power Congress will be held in Washington, D. C., beginning Labor Day, September 7, under the auspices of the United

States. HAROLD L. ICKES is chairman of the American National Commmittee, Interior Building, Washington, D. C. National problems and policies concerning the organization, management, planning, and control of the entire power economy will be considered. President R. D. REED has appointed L. C. SNIDER and A. A. BAKER as Association delegates. Paper No. 12 on the program is "Conservation of Petroleum and Natural Gas," by the United States Bureau of Mines.

The eastern district division of production of the American Petroleum Institute held its annual meeting in Pittsburgh, Pennsylvania, at the William Penn Hotel, June 4 and 5. Among the geologists on the program were K. C. HEALD, J. G. MONTGOMERY, JR., J. FRENCH ROBINSON, PAUL D. TORREY, JACK GADDESS, R. B. NEWCOMBE, WILBER STOUT, C. B. MCCLINTOCK, C. R. FETTKE, C. D. HUNTER. K. C. HEALD presented a paper, "Deep Well Drilling Problems and Their Solutions," and WILBER STOUT a paper on "Petroleum Geology of Ohio."

W. M. PLASTER, of Meeker, Oklahoma, is working for the Ramsey Petroleum Corporation.

The fourth annual Petroleum Conference of Indiana-Illinois, sponsored by the Illinois-Indiana Petroleum Association, the Illinois Geological Survey, and the Indiana Division of Geology, was held at Robinson, Illinois, June 6. The morning session included the following papers: "Geology and the Oil and Gas Possibilities of the Illinois Basin," by J. MARVIN WELLER; "Seismograph Methods Applied to Finding Oil Structure," by FRANK W. DEWOLF; "Demonstration of Core Tests for Permeability," by R. J. PIERSOL. The afternoon session was an informal discussion of the operating problems.

C. W. WILSON, JR., of the geological faculty of Vanderbilt University, Nashville, Tennessee, is at the Yellowstone-Bighorn Research Camp, Red Lodge, Montana, until September.

H. A. IRELAND, recently of the University of Oklahoma and the University of Chicago, is at Spartanburg, South Carolina, during the summer.

JOHN M. HERALD, consulting geologist, has moved from Cleo Springs to 2719 East Fourteenth Street, Tulsa, Oklahoma.

The Mexican Geological Society has been reorganized at Mexico City with the following officers: president, JOSÉ G. AGUILERA; vice-president, MANUEL SANTILLÁN; secretary, EZEQUIEL ORDOÑEZ; pro-secretary, JENARO GONZÁLEZ R; treasurer, ENRIQUE M. GONZÁLEZ. The first meeting of the reorganized society was held on April 30 at the Geological Institute, Calle Cipres 176.

E. E. LINDEBLAD may be addressed in care of the Continental Oil Company, Ponca City, Oklahoma.

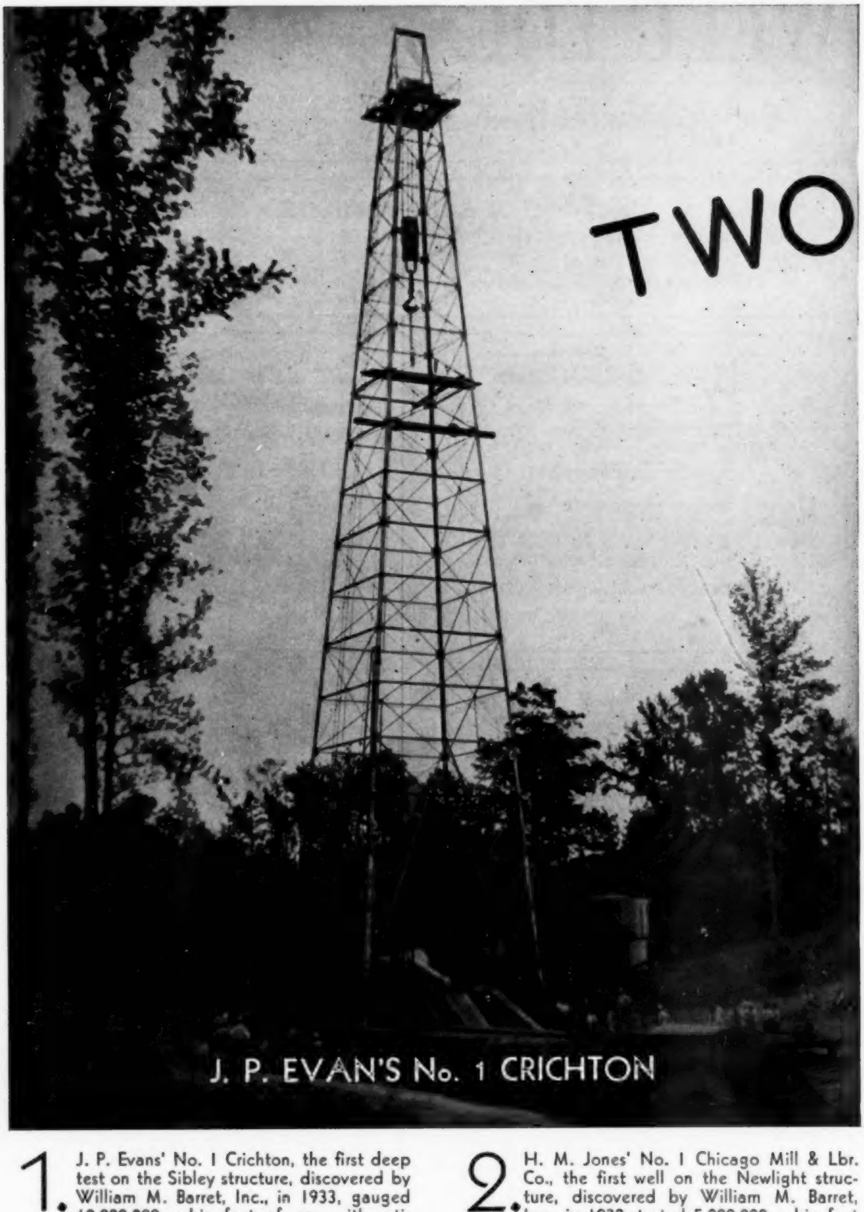
The Tulsa Geological Society held its annual baseball game, picnic, and dance at Mohawk Park, Tulsa, May 22. On May 25, the six geologic sound films, loaned by the United States Park Service and used at the Society's exhibit at the International Petroleum Exposition, were shown at the regular Society meeting.

At its meeting in April, 1936, the committee on grants-in-aid of the National Research Council made the following awards in the fields of geology and geography. FLORENCE BASCOM, senior geologist, retired, United States Geological Survey, and professor of geology, retired, Bryn Mawr College, "The Petrology, Origin and History of the Pickering and Baltimore Gneisses of Eastern Pennsylvania"; KENNETH E. CASTER, assistant head of science department, Geneseo State Normal School, New York, "The Stratigraphy and Paleontology of the Pocono Formation of Pennsylvania and Adjoining Areas"; ERNST CLOOS, lecturer in geology, Johns Hopkins University, "The 'Martic Overthrust' and the Age of the Glenarm Series in Pennsylvania and Maryland"; DAVID M. DELO, instructor in geology, Lawrence College, "Existing Types of All North American Species of the Phacopid Trilobites"; ELEANORA B. KNOPF, United States Geological Survey, "Internal Evidence of the Mechanism of Plastic Deformation of Marble"; WALDEMAR LINDGREN, professor emeritus of geology, Massachusetts Institute of Technology, "Annotated Bibliography of Economic Geology"; CHESTER R. LONGWELL, professor of geology, Yale University, "Preparation of a Tectonic Map of the United States"; F. J. PETTIJOHN, assistant professor of geology, University of Chicago, "Correlation Studies in the Archean of Northwestern Ontario"; V. C. STECHSCHULTE, S. J., professor of physics, Xavier University, "Study of Deep-Focus Earthquakes"; W. T. THOM, JR., professor of geology, Princeton University, "Structural Geology of the North-Central Rocky Mountains and of the Northwestern Great Plains Region." Since the funds which have been placed at the disposal of the National Research Council during the past few years for the making of research grants have been discontinued, there will be no further meetings of the committee on grants-in-aid.

PHILIP B. KING, of the United States Geological Survey, presented results of his work on the Permian Rocks of the Southern Guadalupe Mountains of eastern New Mexico and western Texas, before a special meeting of the Tulsa Geological Society, June 8.

A report privately printed by Oil Search, Limited, entitled "Copy of Report Received by Oil Search, Limited, from the Minister of the Interior (Honble. T. Paterson) following the Inspection of Arcadia and Hutton Domes, Queensland, by the Commonwealth Geological Adviser (DR. W. G. WOOLNOUGH)," contains the following statements, "Deep drilling at Roma has definitely proved the existence of petroliferous conditions in the rocks of the area, and justified prolonged and detailed search for flow oil within the region. . . . Theoretical considerations suggested that the Kamilaroi (Permo-Carboniferous) marine formations outcropping about one hundred miles north of Roma, and presumably existing underground at points much nearer, were the source rocks of the oil and gas. . . . Ideally perfect domal structures have been proved to exist at Hutton Creek and at Arcadia. . . . At no time in the history of the search for oil in Australia have so many completely favourable factors been presented simultaneously by any project." The report is dated April 7, 1936.

R. A. STEINMAYER, head of the department of geology, Tulane University, New Orleans, was recently elected president of the Swiss American Historical Society of Louisiana.



1. J. P. Evans' No. 1 Crichton, the first deep test on the Sibley structure, discovered by William M. Barret, Inc., in 1933, gauged 60,000,000 cubic feet of gas, with estimated 500 barrels of 54 gravity distillate per day, from the lower Glen Rose section (Lower Cretaceous) at 5590 feet.

2. H. M. Jones' No. 1 Chicago Mill & Lbr. Co., the first well on the Newlight structure, discovered by William M. Barret, Inc., in 1932, tested 5,000,000 cubic feet of gas per day, with some oil saturation in cores, from basal Jackson (upper Eocene) at 779 feet.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